GIRDER MAKING

AND THE

PRACTICE OF BRIDGE BUILDING

IN WROUGHT IRON.

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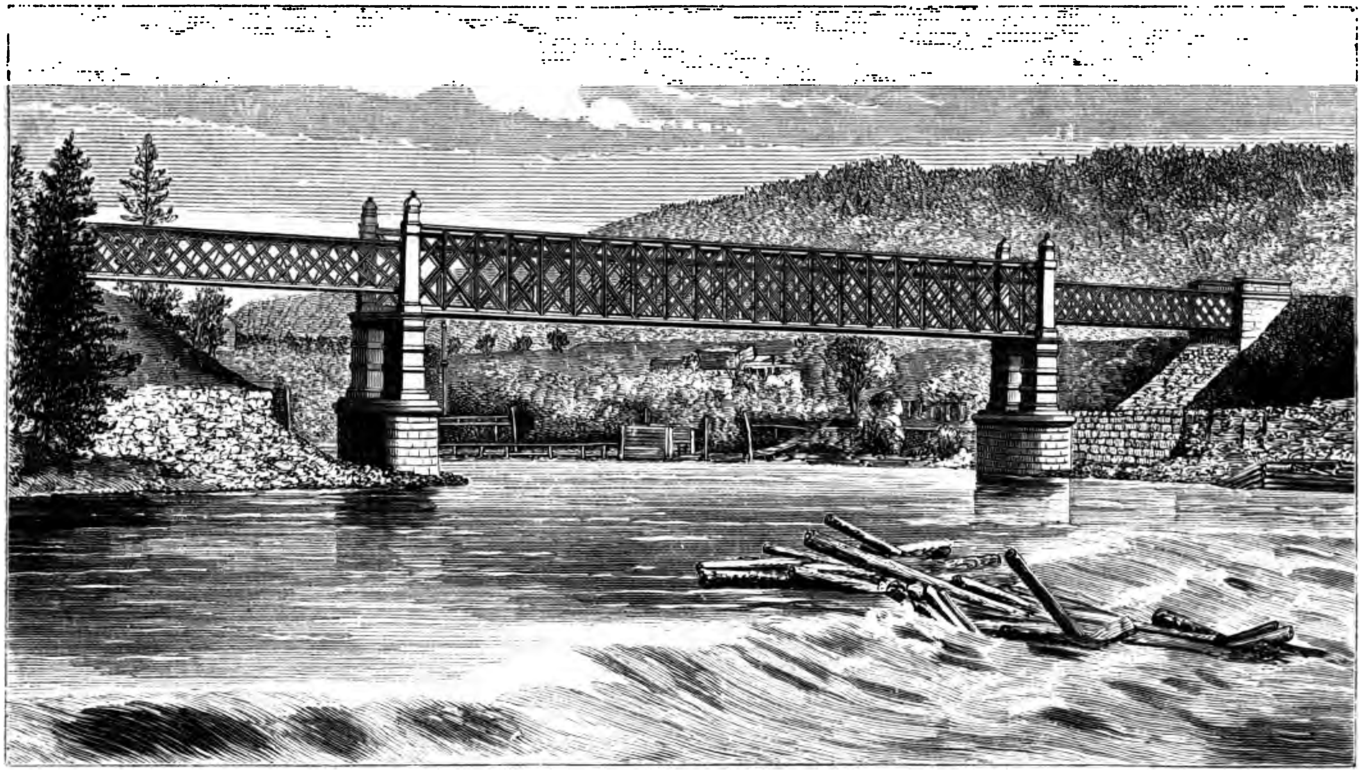

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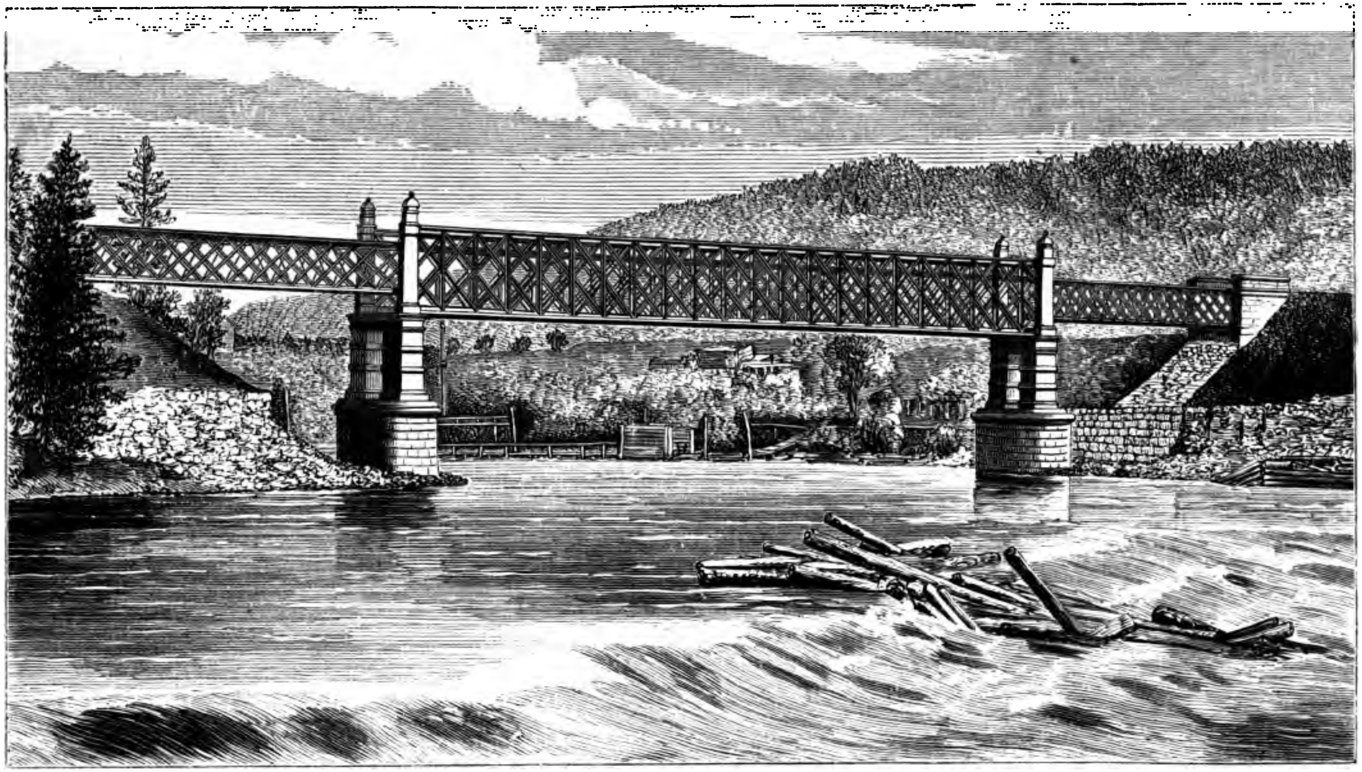

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GIRDER-MAKING

AND THE PRACTICE OF

BRIDGE BUILDING

IN WROUGHT IRON.

ILLUSTRATED BY

EXAMPLES OF BRIDGES, PIER, AND GIRDER-WORK, &c.

CONSTRUCTED AT THE SKERNE IRON WORKS,

DARLINGTON.

BY

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MEMB. INST. MECHANICAL ENGINEERS.

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Preface.

THE writer, in the present work, does not pretend to have any higher aim than to offer a few suggestions of a practical kind to the professional engineer in designing, or the inspector in superintending, the construction of such works as those he has endeavoured to illustrate and describe.

Confining himself exclusively to the practical part of the question, he does not wish to be understood even to have an opinion as to the relative merits of the various designs introduced into the work, further than as these are associated with questions of quality of material, or workmanship; durability as affected by time or exposure; or any other consideration of a purely practical character.

In recapitulating, however, many of the difficulties, and in trying to point out some of the sources of needless expense, in the construction of Girders, a little may be done, it is hoped, towards promoting a condition of mutuality between engineer and contractor; and that whilst the former will be able to get what he requires at *less cost and of a better quality, the latter will find more satisfaction, both in the work he produces and the profit it leaves him, by attention to such questions as the writer has endeavoured to give prominence to.*

With the exception of Mr. Matheson's admirable "Works in Iron" (to which elaborate treatise the writer acknowledges his indebtedness for some valuable hints), but few essays have been made in this direction; and whatever want of ability in dealing with his subject the writer may betray, he can hardly be accused of dwelling upon an exhausted theme.

Restricted as the notice altogether is to such works as have been executed at, or in connection with, the Skerne Iron Works, the several types of Girder-bridge are not, perhaps, so fully represented as they would otherwise have been; but they will, no doubt, for the present purpose be found sufficiently varied and numerous.

The writer trusts he will not be deemed to have exceeded the limits of propriety in briefly noticing works, in one or two instances, without the express sanction of the engineer to whose designs they were carried out. In all such cases he has refrained from giving details, dimensions, or drawings to scale.

List of Plates.

PART I.

THE MATERIALS.

The Construction of Wrought-Iron Girderwork.

PART I.

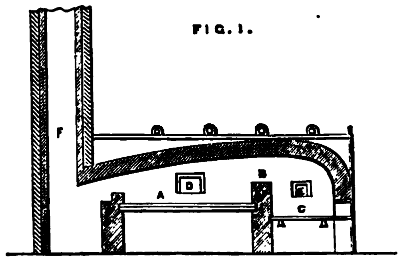
THE MATERIALS.

THE conversion of crude pig iron into malleable or wrought iron has, up to the present time, been almost universally accomplished by the well-known process of puddling; under which operation most of the carbon is separated in a gaseous state, whilst the alloyed metals (phosphorus and other impurities), existing to a greater or less extent in most of the ordinary qualities of pig iron, pass away in the cinder or slag.

Although a great deal of attention has of late been given to the subject, many ingenious machines devised, and some to a limited extent applied, puddling is still a manual operation; the saving in labour, &c. effected by the use of Dank's or other machinery not being deemed by most iron manufacturers commensurate with its great cost; and whilst the material produced by such machinery is generally believed to be of excellent quality, there are many difficulties to be overcome in applying it to mills where a variety of sections are rolled, and the changes necessary in the size and weight of the blooms are very frequent and considerable.

Figure 1 shows an ordinary puddling furnace in section.

FIG. 1.



A steam-worked rabble, however, is now not unfrequently used, conducing at once to the relief of the operative, and a great improvement in the quality of the iron produced; as by means of this appliance pig iron containing a much larger percentage of carbon may be puddled, thus prolonging the boiling part of the process, whilst by a more thorough stirring the oxydising influence of the air and slag are brought to bear more effectually on every particle of the molten mass.

The quality of pig iron usually puddled in the manufacture of such iron as is suitable for girder-making—that is, of plates, angle, tee iron, &c.—is that known as "Forge 4," mixed sometimes with a little "mottled," a quality containing somewhat less carbon; or even a proportion of "white," containing a minimum of carbon. The proportion in which these various qualities are combined in the puddling must be left to the judgment of the forge manager, who will not unfrequently find that the product is improved, rather than deteriorated, by a judicious admixture of what appears to be a lower, but not necessarily more impure, quality of pig.

When the mechanical·rabble is used, a proportion of "Foundry 4" may be used with benefit to the charge, the result being probably a softer and more ductile material than when the molten pig is of a less fluid nature.

The iron of the Cleveland district being, as is well known, of a somewhat hard and "cold short" nature, it is usual, in order to remedy this defect, to introduce a mixture possessing opposite qualities; the most suitable for the purpose being the red hæmatite of Cumberland and Westmoreland. This may be done, either by combining the ores in the blast-furnace, or by mixing the pig-iron in puddling, the results being equally good whichever plan is adopted.

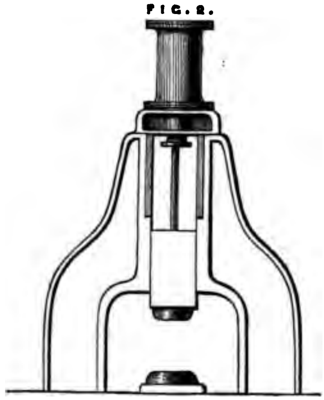
Malleable iron made from hæmatite pig-iron alone is extremely ductile when cold, but it is "red short;" that is, it will not forge well, and is friable and weak when at a red heat.

It is usual to charge the ordinary single hand puddling furnace with from 4¼ to 4½ cwts. of pig-iron at a time. This is called a "heat," and six "heats" are worked in a "shift" of twelve hours.

From these six heats from 22 to 25 cwts. of puddled iron is produced, the exact quantity depending upon the skill of the puddler and the quality of the material—pig-iron, coal, and oxide—supplied to him.

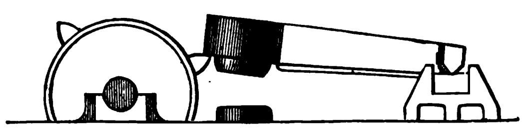
For the sake of convenience in manipulation, each "heat" when ready to be taken out of the furnace, is divided by the puddler into several "balls." These balls are brought out of the furnace singly, but are welded together in batches of two to five under the shingling hammer (Fig. 2).

FIG. 2.



It is highly important that the balls should be welded together whilst at a high temperature, otherwise a film of infusible scale will form between them, and resist all subsequent attempts to weld the iron into a homogeneous mass.

FIG. 3.



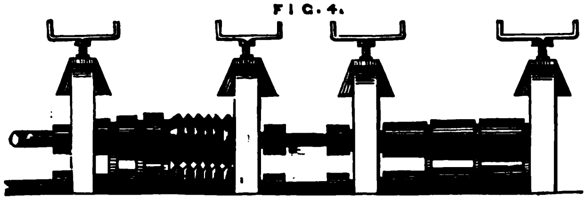
This is a common cause of unsound and laminated iron, and is especially the origin of unsound plates.

Before the steam-hammer was used in shingling, and when the old-fashioned tilt-hammer, or helve (Fig. 3), only was known to the iron-maker, it was beyond the power of the operator to regulate the force of the blow given to the piece of iron, and only sound, well-puddled material would bear it without flying in pieces. A pretty uniform quality of iron was thus secured, without much personal supervision on the part of the forge manager.

With the steam-hammer, on the other hand, though the force of the blow may be greatly increased, it is so easily regulated and controlled, that great attention must be given to ensure the thorough hammering necessary to consolidate the bloom and test its malleability.

The puddled bloom now hammered into a rectangular lump, four or five inches in thickness, and from four to eighteen inches wide, according to the purpose for which it is intended, is then passed through the puddling or "forge" rolls (Fig. 4).

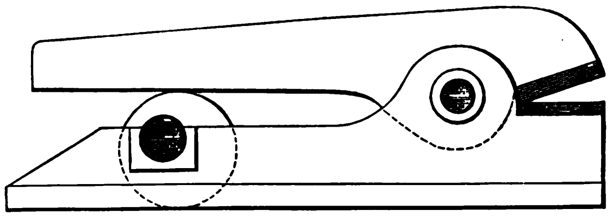
FIG. 4.



These are grooved to form bars of corresponding width, sixteen to eighteen inches wide being used for plates, and narrower grooves, down to four or five inches wide, for bars, angles, &c. of various sections.

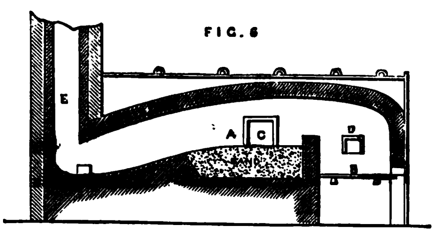
When cold, the puddled bars are cut up by the cropping-shears (Fig. 5) into convenient lengths, and "piled." Piling consists in bundling together short lengths of puddled bar, with a certain proportion of scrap iron, each pile being adjusted as regards its weight, so as to produce a plate or bar of the desired size, allowance being made for waste by oxidation, &c.

FIG. 5.



in the re-heating furnace (Fig. 6), and in cutting the rough bar or plate to the finished length or size.

The admixture of scrap is considered, generally speaking, to have an improving effect upon the quality of the finished iron; but this manifestly depends upon



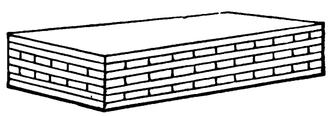
the relative qualities of the puddled bar and the scrap iron to be used with it.

Old double-headed rails, for instance, sometimes largely used, will generally tend rather to deteriorate than improve the finished iron; but these, again, vary so in quality that no strict rule can be established. *Very* old rails are of good quality, and those at present made are tolerably so; but fifteen or twenty years ago anything was thought good enough to make rails of, and a great deal of such iron is now being returned to the mills as scrap.

Mixed scrap generally softens and improves Cleveland iron, and should always be used as largely as circumstances will admit of; but in rolling plates which have to be sheared all round, the resulting scrap is generally found to be nearly as much in quantity as it is practicable to pile in, as an average of about one-third of the rough plate must be clipped off to bring it to the dimensions required, and to ensure a sound and perfect edge.

In order to produce plates of great tensile strength, and especially for such as are required to be equally strong in both directions of the fibre, or with and across "the grain," as it is termed, cross-piling is practised (Fig. 7).

FIG. 7.



This consists in placing the bars of which the pile is composed in each direction alternately, frequently omitting the scrap altogether.

In order to produce a clean surface, it is essential that the top and bottom of the pile are each composed of one slab of puddled iron, though it is possible to make a tolerably sound plate with the top and bottoms of the pile formed of narrow bars placed side by side. The immediate layers may be made of bars of any convenient width.

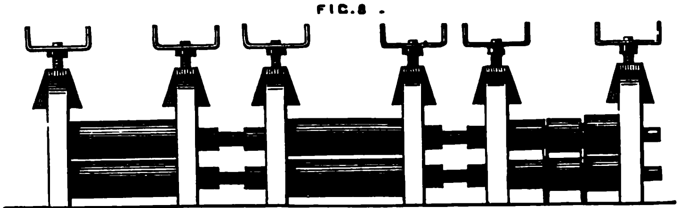
For angles, tees, &c., as well as sometimes for plates, the piles are formed with the edges solid as well as the top and bottoms, the interior being filled with rough, small scrap. This is called box piling. The objection to box piling for plates is that the solid edges of the pile tend to prevent any cinder or foreign matter, which may have been associated with the scrap, from squeezing out at the edges under the pressure of the rolls. This mode of exit being impracticable, the cinder, &c. is apt to appear on the surface of the plate in a "blister or scab."

For angles, tees, &c. it is necessary to build the piles of various qualities of puddled bar, so arranged in relation to each other as to give ductility or hardness, as the case may be, where it is most required; and in plates an attempt is often made by means of special piling to secure a somewhat hard, unyielding interior with a soft and ductile surface. This is done where engineers' specifications require plates of great tensile strength, at the same time possessing bending qualities, or other indications of malleability; but carelessness in the re-heating process will entirely defeat this object, and the better the quality of the exterior of the iron, the more likely it is, within certain limits, to be burnt, or "caught," as the workmen term it, in the re-heating furnace.

The piles for plates, as well as for all iron of large section, is generally in the first instance charged into what is curiously called in the North of England a "cold-heating" furnace, the term being a relative one, and implying that the temperature is not so high as that of the "wash-heating" furnace, in which it is finally placed after having been rolled down to a slab of two or three inches in thickness. "Cold-heating" furnaces may have either "dry bottoms" or "wet bottoms," each class possessing merits of its own, but the difference is not of such importance as to require explanation here.

As soon as the piles in the "cold-heating" furnace reach a welding heat, they are drawn, and subjected

FIG. 8.



C B A

to the action of the "blooming rolls" (A, Fig. 8), after which, being now somewhat elongated and solidly compressed, they are put into the wash-heating furnace, and when drawn are rolled down to the thickness required in the "soft" and finishing rolls (B & C).

For large or thin plates and angles, and bars of great width, an intense heat is necessary to prevent the edges cracking in the case of bars, or the surface breaking up in that of plates, before the pile can be brought down to its required dimensions.

When reduced to the specified size, the bars or plates are roughly straightened with wooden mallets, and laid on the floor to cool. They are then cut to the specified sizes, and are ready for use.

The value of manufactured iron for girder-making purposes may be said to depend upon its possessing in a greater or less degree the following qualities :—

1. Strength when subjected to tensile strain.
2. Strength when subjected to compressive strain.
3. Ductility when cold.
4. Malleability when hot.

To these might perhaps be added, a high "limit of elasticity," but the introduction of such a term is of doubtful practical utility, and it is seldom found in engineers' specifications for girder-work.

An examination of any of the numerous tables which have of late years been published in various works on engineering subjects, notably those by Mr. Kirkaldy, will tend to show that as regards the simple strength of wrought rolled iron, whether subjected to a tensile or compressive strain, the difference between iron of the highest class and that of what are usually known as inferior brands, is not great.

The better samples of commoner brands will generally bear in tension about twenty tons to the square inch, whilst it would hardly be safe to calculate upon much more than this, whatever brand might be specified, or whatever price was paid for the iron, unless each individual bar or plate could be separately tested. With regard to ductility when cold or hot the difference is more considerable, but not so much so as to render the use of high-class iron either necessary or economical, and iron made from Cleveland pig, with a certain admixture of hæmatite or other iron of a softening tendency, can hardly be surpassed, when its price is considered, for girder-making purposes.

It may, indeed, be questioned whether any considerable proportion of such structures is made in this country at the present time of other than Cleveland iron, or a mixture of it with other brands; as this iron is now imported into almost every iron-producing district to be puddled, either alone or in combination with the native pig.

An exception may perhaps be made with regard to Derbyshire and North Staffordshire, where a good deal of iron suitable for girder-making is manufactured from the native pig, with but small admixture of foreign iron.

In estimating the strength of wrought-iron riveted structures, it is usual to consider the breaking strain of plate-iron at about twenty tons per square inch of sectional area with, and about eighteen tons across the grain respectively.

All iron should stand this, but whatever brand may be used it would hardly be safe to calculate upon much more.

Bar, angle, and other narrow sections are generally required to stand two or three tons more; but, taking into consideration the greater liability that exists in all narrow sections to accidental defects and injury in manipulation, it is safer not to calculate upon any great superiority over plates, and to adhere to the twenty tons per square inch as the all-round standard.

To judge of the quality of bar or plate iron by the appearance of the fracture, requires a somewhat practised eye. It is seldom that iron showing a bright fibrous fracture throughout can be obtained at such a price as will render it available for girder-making, nor is it at all necessary that it should be so.

The tensile strength, or limit of elasticity, of such iron is not found to be so great as that with a somewhat crystalline fracture.

There should, however, be no appearance of crystallisation at or near the surface of the iron, nor should it be in one thick layer, but rather intermingled with the fibrous portion.

It may be assumed that a bar or plate showing in fracture about one-third of crystallised iron, will sustain a greater weight per square inch of sectional area than it would if the whole were fibrous and of the same quality. The crystals of iron should be small and bright, and square rather than elongated, the latter form indicating an excess of phosphoric acid, than which nothing tends more to undue hardness, and all the defects of "cold short" iron; nor should they be *very* small or black-looking. When the fracture shows a fibrous interior, with crystalline surface, it indicates that the pile has been exposed to too great a heat, or, what is perhaps more likely, that it has been allowed to remain too long in the furnace. Such iron works very badly, and should always be rejected by the inspecting engineer.

The worst quality of all is that which appears fibrous throughout, but is very dull and black-looking, instead of having a bright silky fibre.

Such iron has no "nature" in it, and has been bad from the beginning. It will not stand working either hot or cold, and its strength in tension is always very low.

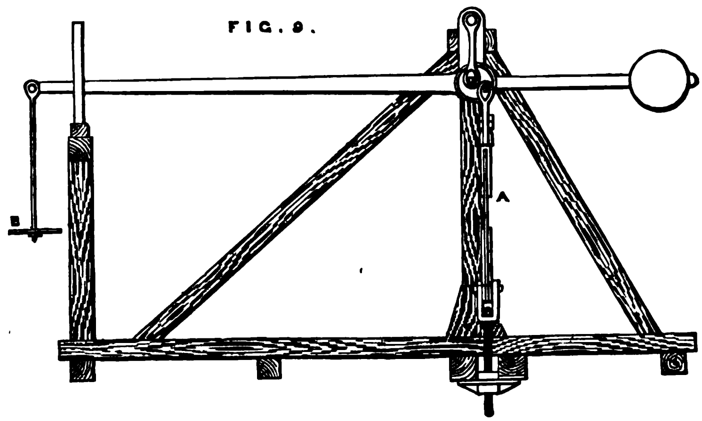
The surface defects on plates or bars are generally of small importance with regard to their suitability for girder-making.

They generally indicate, indeed, a tolerably tough and fibrous quality of iron, which is much more likely to "shell" and "blister" than is iron containing more cinder, and therefore of a shorter and weaker nature.

When the plate or bar is rough and scaly, it shows that the rolling process has been completed at too high a temperature: or that the scale, formed in rolling, has not been properly brushed off as fast as formed; it has but little to do with the quality of the material itself.

The most satisfactory mode of testing rolled iron for tensile strength is by means of a simple lever, of

FIG. 9.



such strength and proportions as to pull asunder a bar of not less than half a square inch of sectional area (Fig. 9). Hydraulic testing-machines are sometimes used. They are extremely convenient, and in some respects superior to the common lever machines; unless in constant use, however, and well cared for, they are liable to get out of order, nor can their accuracy be so easily proved by the inspector as that of a machine of simpler construction, which is, therefore, to be preferred for ordinary use in the bridge-yard.

No test-bar should be sheared, bent, or hammered, either hot or cold, but the part to be pulled asunder should be reduced to the required sectional area by planing, drilling, or filing, and, except for special purposes, the test bars of plates should not be cut from the extreme edge of the plate.

Iron is usually rolled as bars, that is in grooved

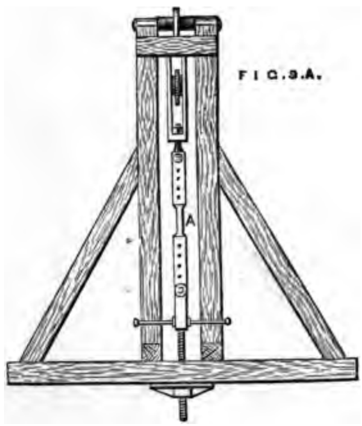


FIG. 3 A.

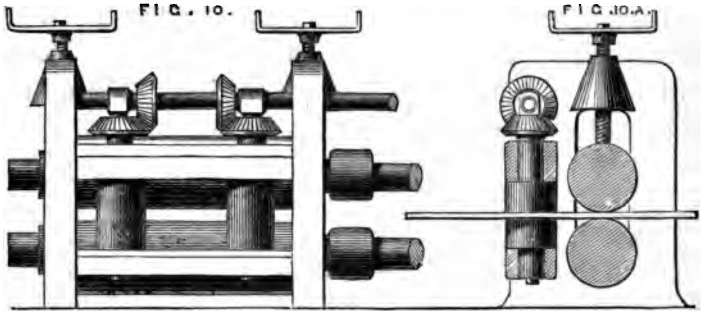
rolls up to eight inches in width, when it exceeds eight inches as plates.

This is an old rule, however, "more honoured in the breach than in the observance." On account of the increased cost, whether rolled as bars or plates, it is best to avoid, as far as possible, the use of long strips from seven to twelve inches wide, especially if less than three-eighths of an inch in thickness. All iron manufacturers dislike equally wide bars and narrow plates.

Flats, up to about twenty inches wide, are rolled in Belgium, Germany, and France, but owing, no doubt, to the state of the "labour question" rendering the introduction of any novelty a matter of great difficulty and risk, this branch of the Iron trade, like that of rolled joists, has received but little attention in this country; and even during the present period of extreme depression, joists and flats, the former especially, are imported from Belgium in large quantities. Flats, however, up to thirty inches wide, are now made by the Skerne Company.

They are rolled in what is called the "universal

FIG. 10. FIG. 10.A.



mill" (Fig. 10), and can be varied in width to a nicety.

They are extremely convenient for forming the flanges of girders, &c. as the waste, often amounting to 10 per cent., as well as the time and cost of planing the edges of the strips, is saved.

Plates are now generally rolled without extra charge above the market price up to eight or nine cwt., and up to about four feet in width. This applies only to the ordinary ship or girder qualities.

Plates thinner than three-sixteenths of an inch are usually charged for at an extra price, nor is it advisable to introduce any as thin as this, if of large area. They are expensive to roll and difficult to manipulate afterwards. A plate three-sixteenths of an inch thick will virtually cost about as much as one of the same superficial area a quarter of an inch thick.

Thin sections of angle, tee iron, &c. are equally to be avoided as far as possible, especially if they are required to bear "cranking," "joggling," or bending. For these purposes bars should hardly be less than three-eighths of an inch thick, and they are better even thicker than this for sound substantial work.

Almost every section of iron produced by the rolling-mill is used more or less in the construction of girders; but in practice the proportions of each may be considered to average as follows :—

Plates	45	per cent.
Angles	25	,,
Flats	15	,,
Tees, channel, beam-iron, &c., &c. ...	8	,,
Rivets	7	,,
	100	

These proportions, of course, vary greatly, according to the kind of girder adopted. Supposing the price per ton of plates to be £10, the value of the other kinds of iron may be taken to be as under :—

Angles and flats	£9	per ton.
Rivets	13	,,
Tees, &c.	10	,,

From this it will be seen that the materials of a girder composed almost entirely of angles and flats, and with but little riveting, would cost nearly £1 per ton less than those of one with the usual proportion of plates, tees, and rivets in materials alone. Girders to a great extent fulfilling these conditions are shown in detail in Figures 11 and 12.

Several thousand tons of these girders were made at the Skerne Works, to the specifications and designs

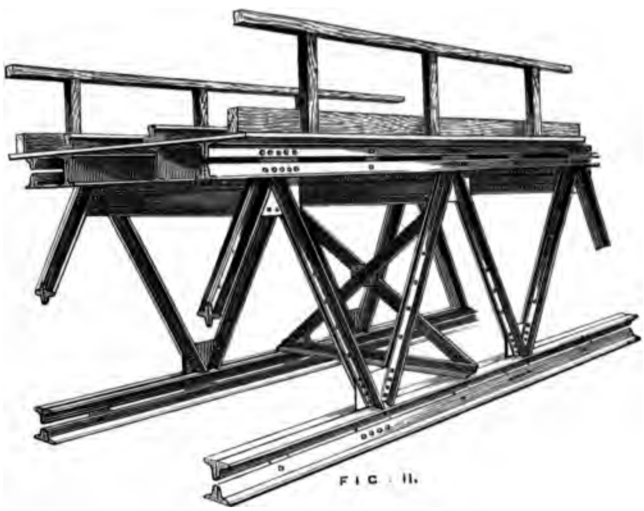


FIG. 11.

of Mr. A. M. Rendel, C.E., for the Indian State Narrow Gauge Railways.

The main bracings of these girders are formed of tee iron; excepting as regards which the designs could hardly be simplified further, whether in point of economy in the use of materials or the cost of labour in construction.

Hardness, viewed as a defect in rolled iron, is of much greater importance in the case of angles and other narrow sections, than it is in that of plates, as the narrower the sections the greater the liability to damage in punching or straightening; but all hard iron is more or less subject to injury in these processes, and cracks extending from the rivet holes to

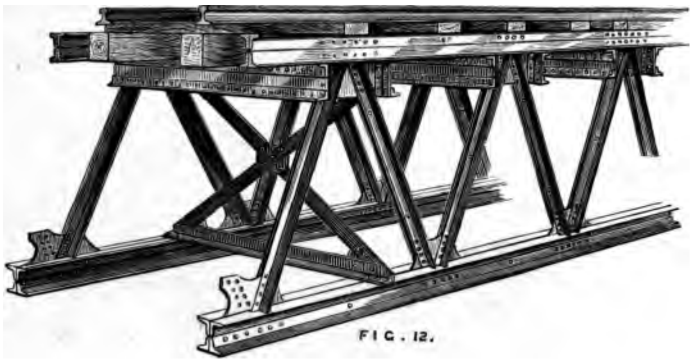


FIG. 12.

the edges of lattice bars, bracings, &c., are amongst the commonest, as well as the most serious, defects in wrought-iron girder-work (Fig. 13). These cracks are often hardly distinguishable. In plates, unless the

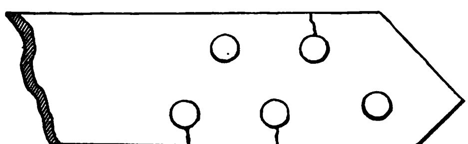


FIG. 13.

rivet-holes are very near the edge, this source of weakness in the girder does not exist, nor is such a defect, usually, of equal importance in a plate as in a narrow bar, where, perhaps, 20 or 30 per cent. of the available sectional area may be lost, and in some cases the strength of the girder itself diminished in the same ratio.

Hard plates may, as a rule, be easily detected by the inspector by their cracking unduly on the edge when being sheared.

Whatever the importance of good materials may be, that of good workmanship is far greater, and if carefully manipulated, girders may be, and are, made of the very commonest quality of manufactured iron, standing perfectly well all ordinary tests and answering all requirements.

In almost all cases of failure, the fault lies either in the design or the construction, not in the quality of the materials of which the structure is composed.

Angle iron may usually be bought about twenty shillings per ton below the price of tee iron of the same sectional area. The demand for angles greatly exceeds that for tees, hence, greater competition and lower cost of production.

In the case of the Indian State Railway girders already mentioned, the cost would have been several shillings per ton less could angle iron have been used instead of tee iron in the main-bracing.

Angles and bars, in most modern mills, may be rolled to any reasonable length, but pieces above thirty feet long become awkward and unmanageable, and the introduction of such should not be more frequent than is necessary where economy is an object.

If the girder, however, is not more than thirty-five or forty feet in extreme length, it will probably be cheaper to make the bars in one length rather than introduce joints and covers.

Unequal sided angle iron is expensive in small quantities, as the demand not being so great, the manufacturer has, probably, to prepare his mill specially for such an order; where, however, the quantity is large, the price should not be higher than that asked for equal sided iron of the same sectional area. All angle and tee iron becomes more costly when under about four and over nine united inches (*i.e.* the width of both or of all the sides added together).

FIG. 14.

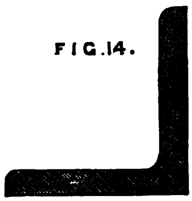
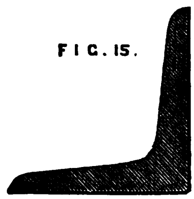


FIG. 15.



The best sections of angle and tee for forming girders are those in which the sides are of equal, or nearly equal, thickness throughout (Fig. 14), not tapered (Fig. 15), or much rounded away at the edge.

FIG. 16.

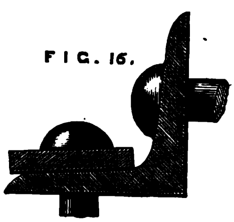
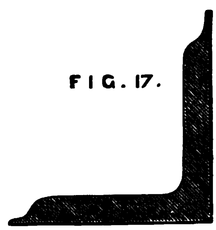


FIG. 17.



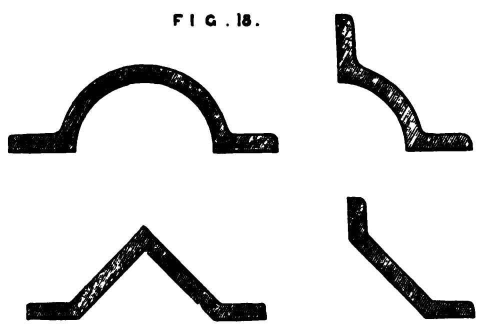
Such as are so never "cover" well (Fig. 16), nor do the rivet heads bear so fairly.

Angles rolled in old or much worn rolls often have a fin along the edge, than which nothing damages the appearance of the work more (Fig. 17).

All sections of rolled iron are expensive in very small quantities for reasons already given, so that in designing girder work with a view to economical execution, it is desirable to introduce as few sections and widths as is consistent with due proportion, although flat bars, and to some extent angles and tees, may vary in thickness without the cost being thereby necessarily increased.

Special sections of iron are sometimes rolled for columns, piles, &c. (Fig. 18). These are always very

FIG. 18.



expensive in small quantities, and sometimes can hardly be obtained at any price within a reasonable time. As in the case of rolled joists, such iron is generally imported from Belgium.

Rivets are necessarily made of iron of a much more ductile quality than that of the plates, bars, &c. They are often specified to be made of scrap, and when this is of good quality the product is correspondingly so. Scrap rivets, however, do not "snap" so easily as when the iron is a little more "cindery;" and for that reason they are objected to by some inspectors of girder work.

Iron either of a "red short" or "cold short" nature is, of course, quite unsuitable for making rivets.

Plates 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 give a few selections of sections of angle, tee, channel, and other iron, suitable for girder construction.

Plate 12 also gives the principal sizes of buckled plates made at the Skerne Works. Most of these can be varied a little in point of size either way, and the cost of preparing dies for special sizes, unless over about four feet square, is not great.

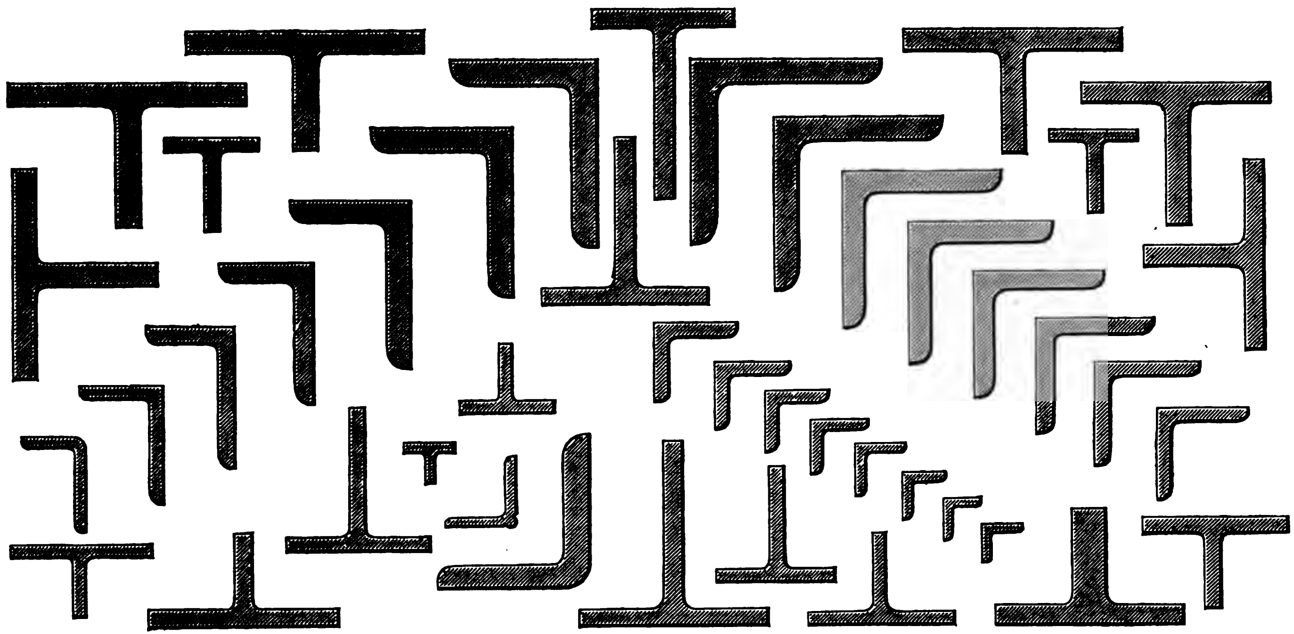
Flooring plates corrugated in a variety of forms are also easily made, at a little over the price of plates in most cases. They are generally stamped hot as the plates come from the rolls.

STEEL IN GIRDER CONSTRUCTION.

To such an extent has the manufacture of cheap steel been developed within the last few years, that in structures of almost every kind where iron has been heretofore exclusively used, steel has to some extent taken its place; and although in this country iron is still in very general use for girder construction, there are not wanting reasons for supposing that, sooner or later, a change in this respect, more or less complete, will come about.

That such has not already been the case is owing to several causes. In the first place the Board of Trade regulations were such as to nullify any advantage which would otherwise result from using a stronger but somewhat more expensive material; as, whatever the strength of the material, a certain sectional area,

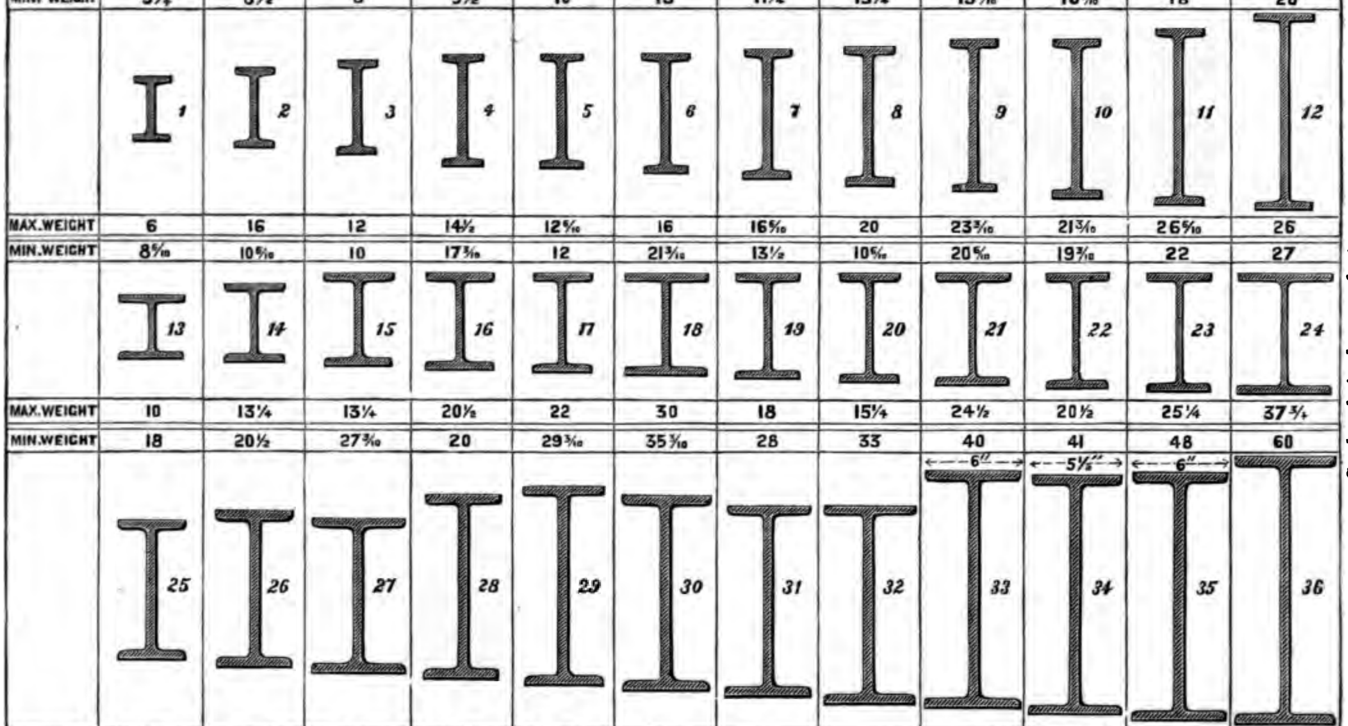
PLATE I.



ONE QUARTER FULL SIZE.

SECTIONS OF ANGLE AND TEE IRON, ROLLED BY WM. WHITWELL AND CO., STOCKTON-ON-TEES.

PLATE 2.



	1	2	3	4	5	6	7	8	9	10	11	12
MIN. WEIGHT	3¼	8½	8	9½	10	13	11¼	13¼	15 3/10	16 6/10	18	20
MAX. WEIGHT	6	16	12	14½	12 9/10	16	16 6/10	20	23 3/10	21 3/10	26 6/10	26

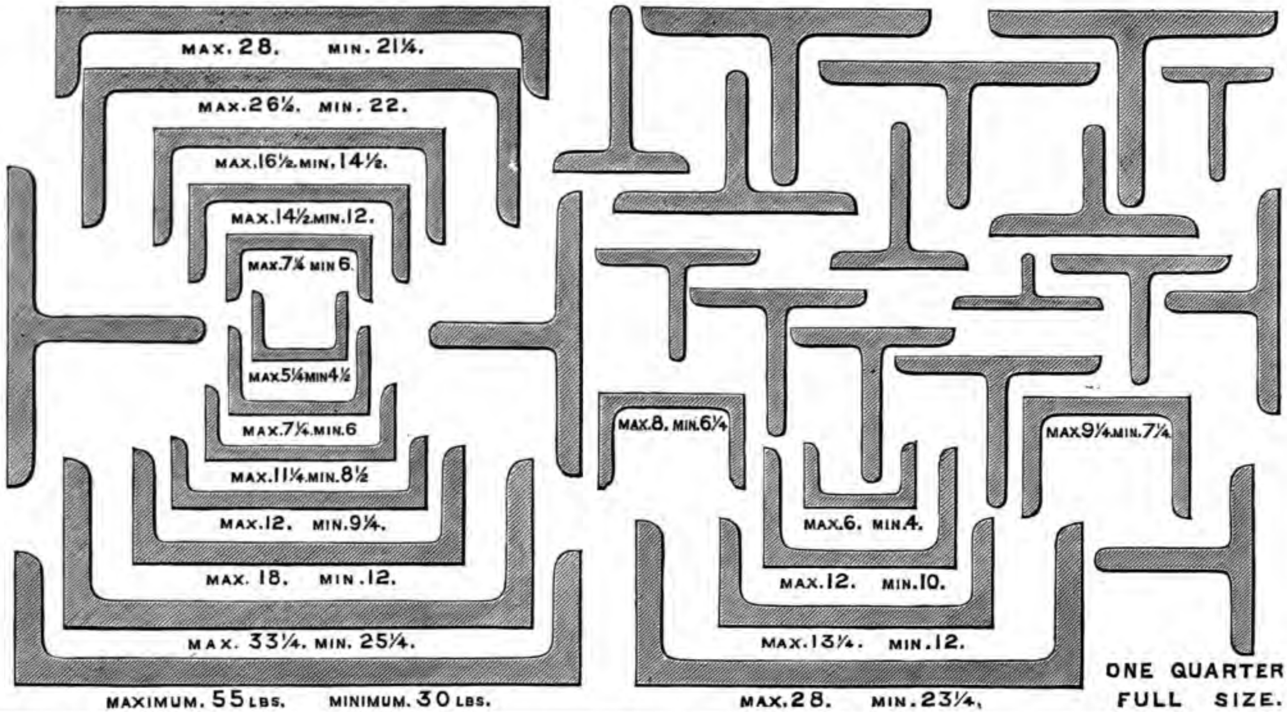
	13	14	15	16	17	18	19	20	21	22	23	24
MIN. WEIGHT	8 6/10	10 6/10	10	17 3/10	12	21 3/10	13½	10 6/10	20 6/10	19 3/10	22	27
MAX. WEIGHT	10	13¼	13¼	20½	22	30	18	15¼	24½	20½	25¼	37¾

	25	26	27	28	29	30	31	32	33	34	35	36
MIN. WEIGHT	18	20½	27 3/10	20	29 3/10	35 3/10	28	33	40	41	48	60
Flange width									6″	5⅞″	6″	
MAX. WEIGHT	24	31 3/10	32 6/10	29 3/10	40	47 3/10	38	45	56	62	53	66 6/10

SECTIONS OF JOIST IRON, FROM THE LIST OF J. S. BERGHEIM AND CO., LONDON.

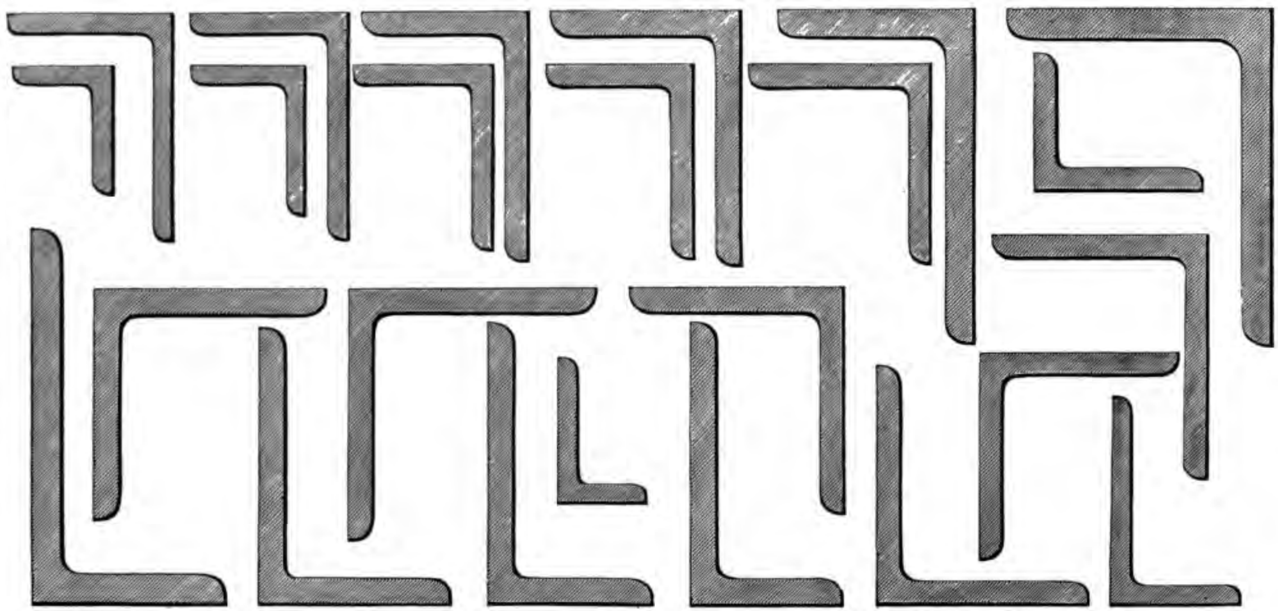
Scale. 1¼ inch to 1 foot.

PLATE. 3.

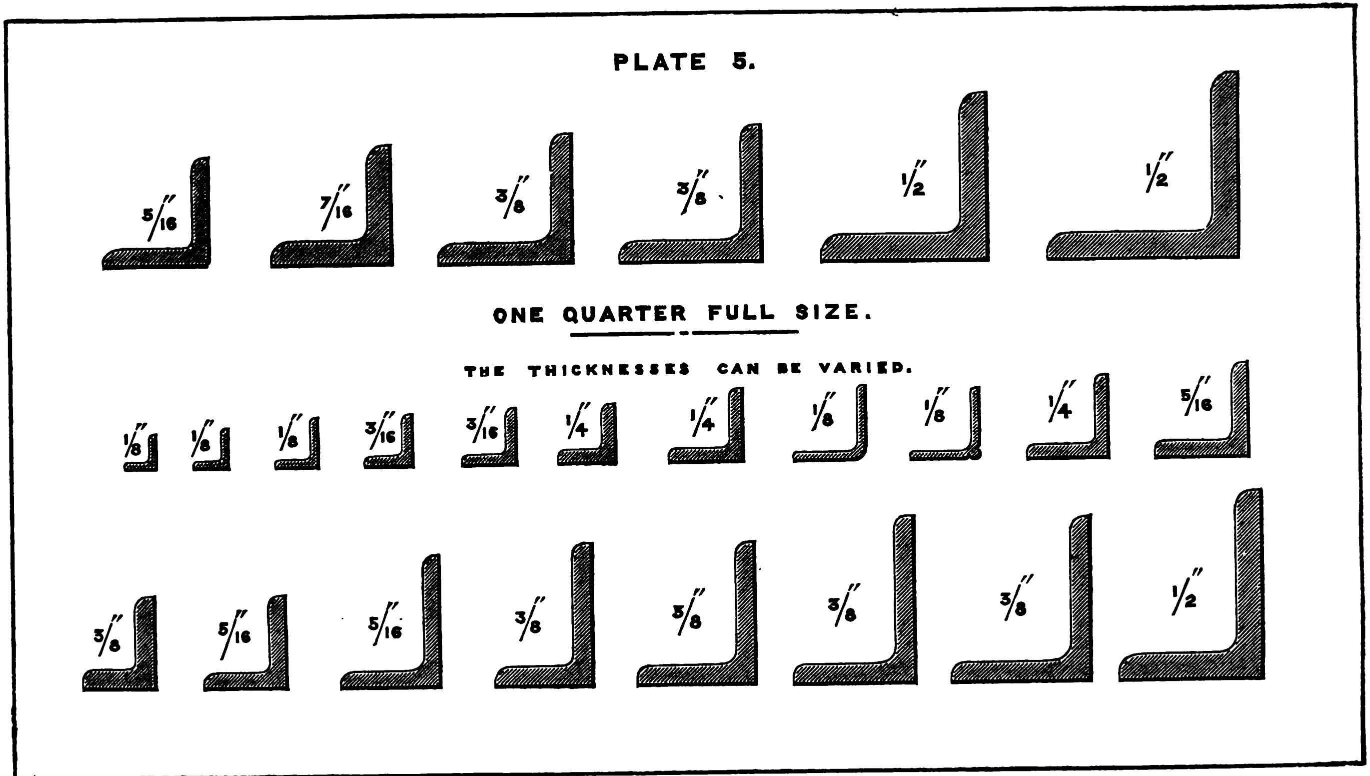


SECTIONS OF TEE AND CHANNEL IRON, FROM THE LIST OF J. S. BERGHEIM AND CO., LONDON.

PLATE 4.

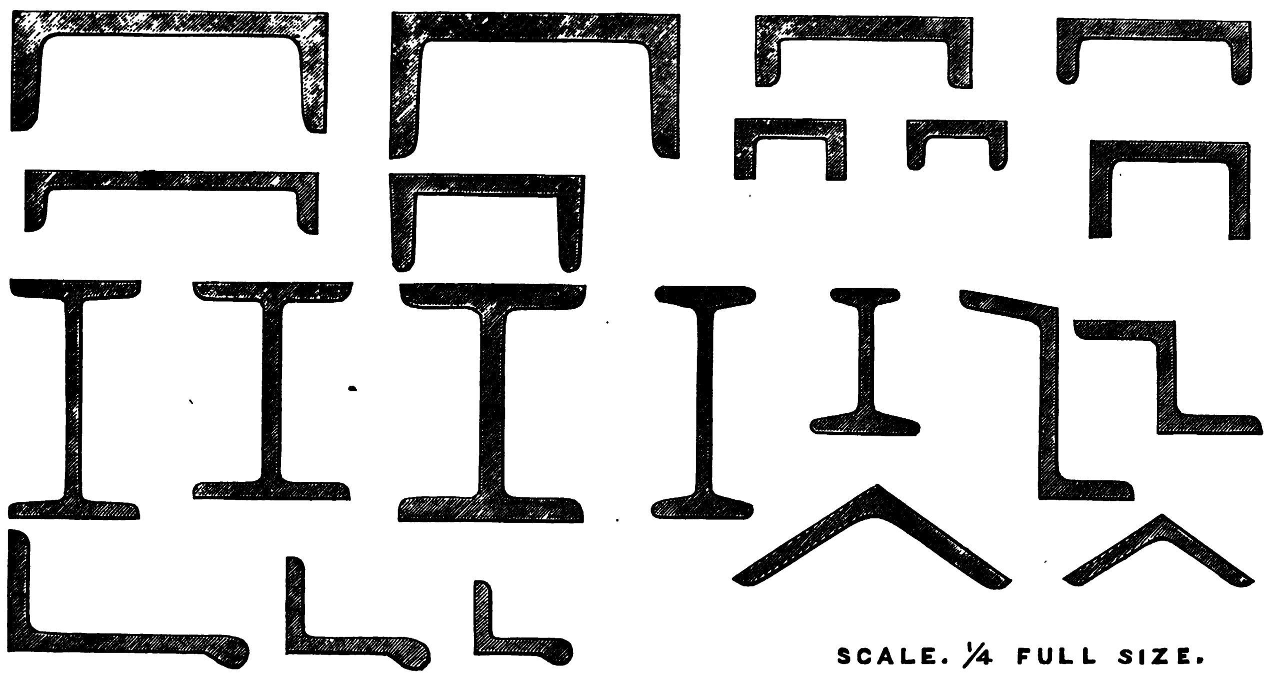


Sections of Angle Iron, from the List of J. S. Bergheim and Co., London.



Angle Iron, from the List of Fry, Ianson and Co., Darlington.

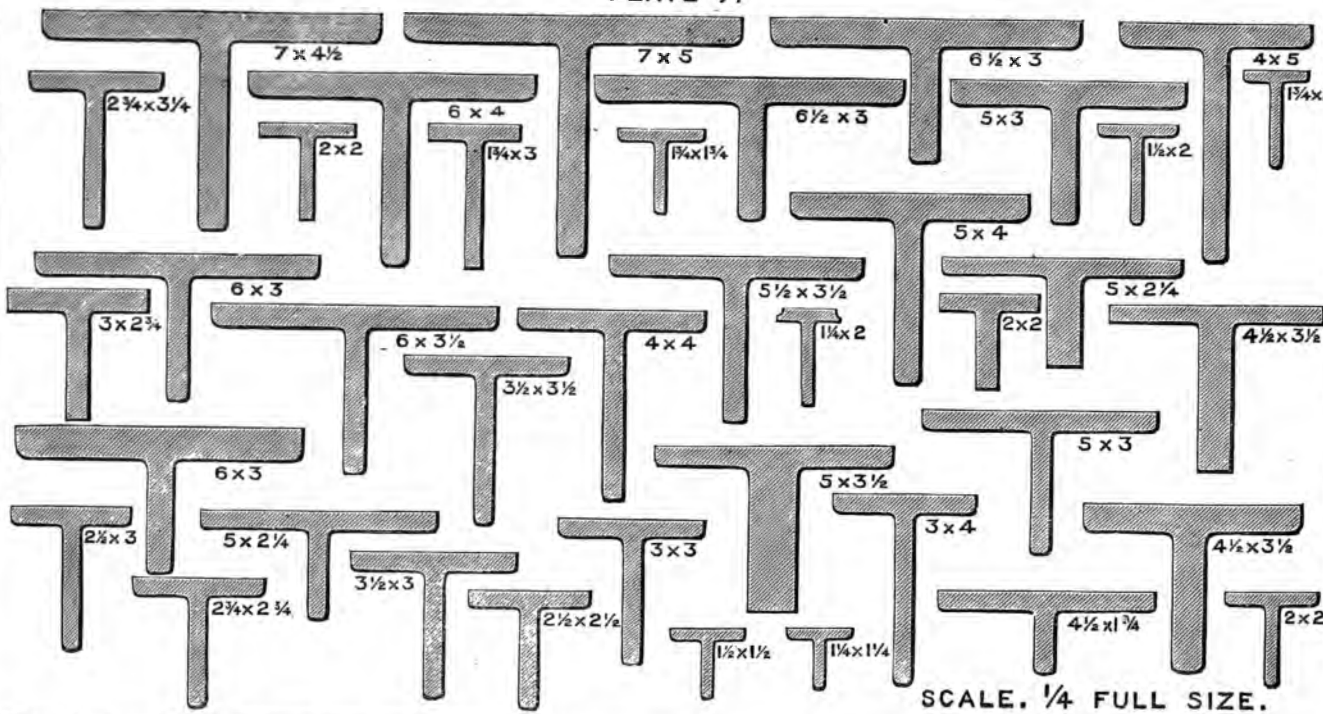
PLATE 6.



SCALE. ¼ FULL SIZE.

SECTIONS OF CHANNEL, H IRON, &c., ROLLED BY JOS. WHITHAM AND SON, PERSEVERANCE IRONWORKS, LEEDS.

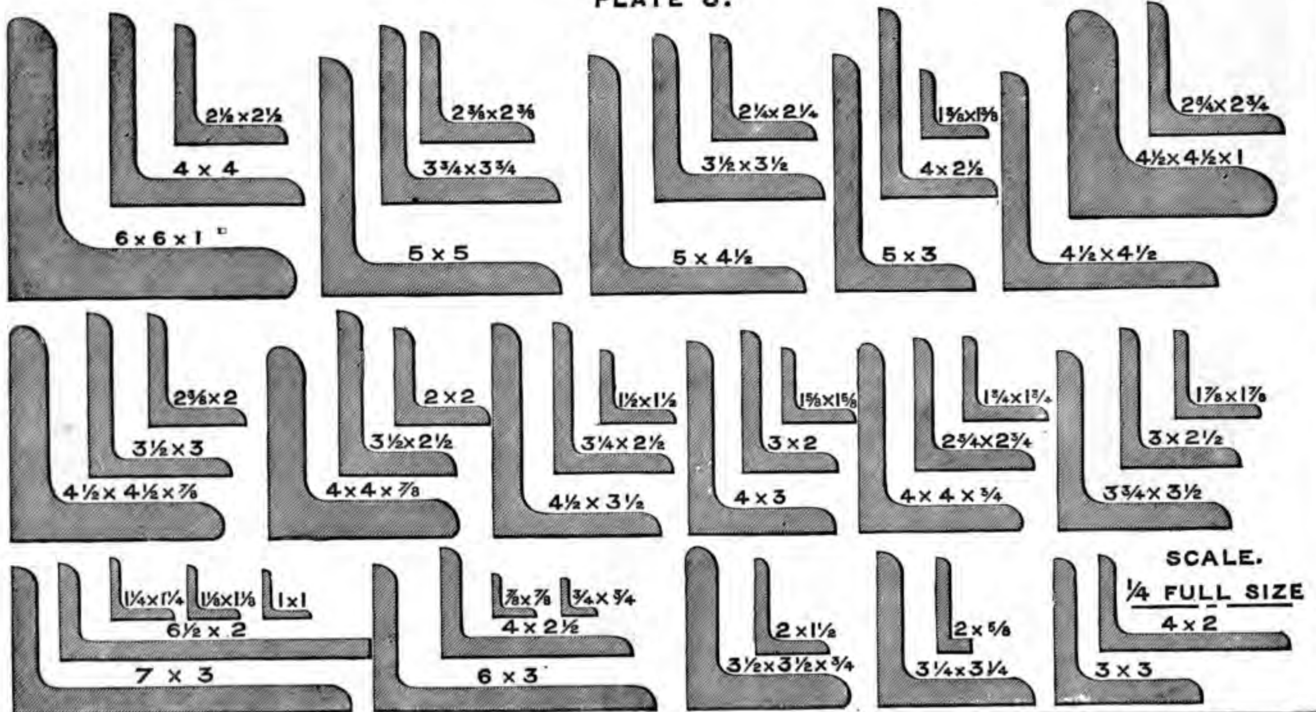
PLATE 7.



SCALE. ¼ FULL SIZE.

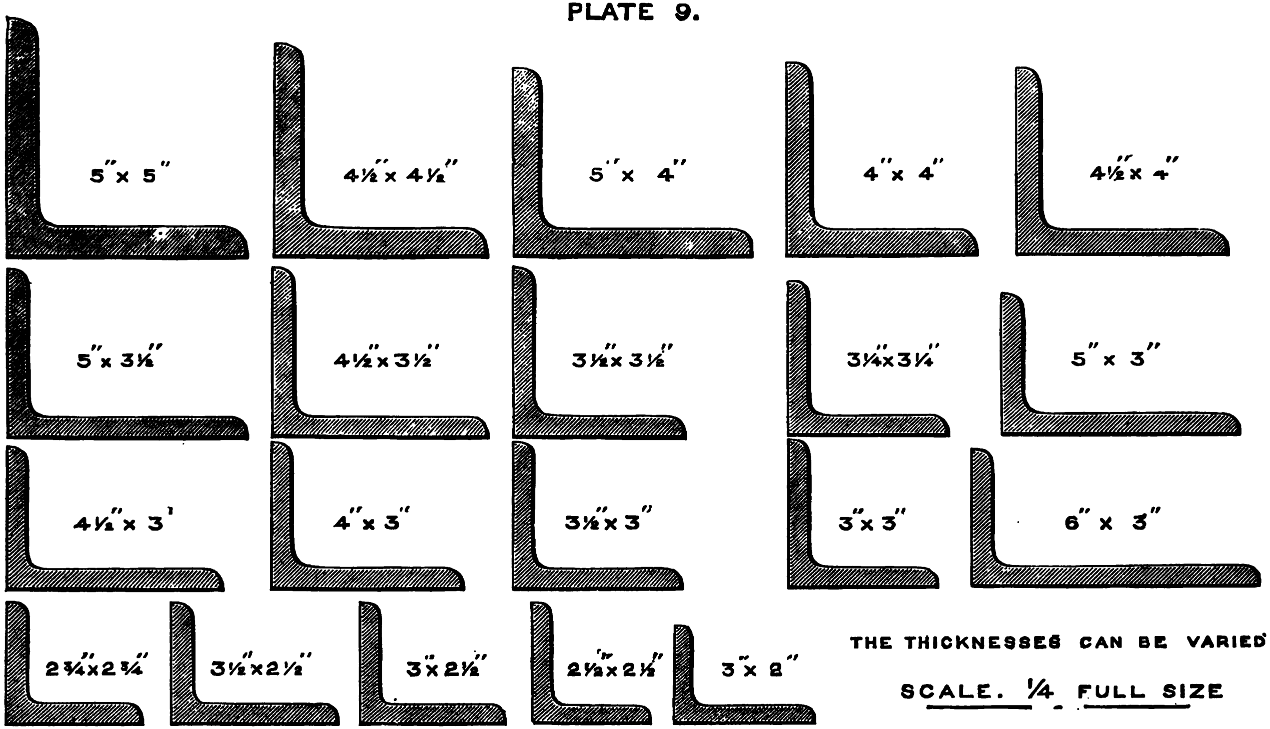
SECTIONS OF TEE IRON, ROLLED BY JOS. WHITHAM AND SON, PERSEVERANCE IRONWORKS, LEEDS.

PLATE 8.



SECTIONS OF ANGLE IRON, ROLLED BY JOS. WHITHAM AND SON, PERSEVERANCE IRONWORKS, LEEDS.

PLATE 9.

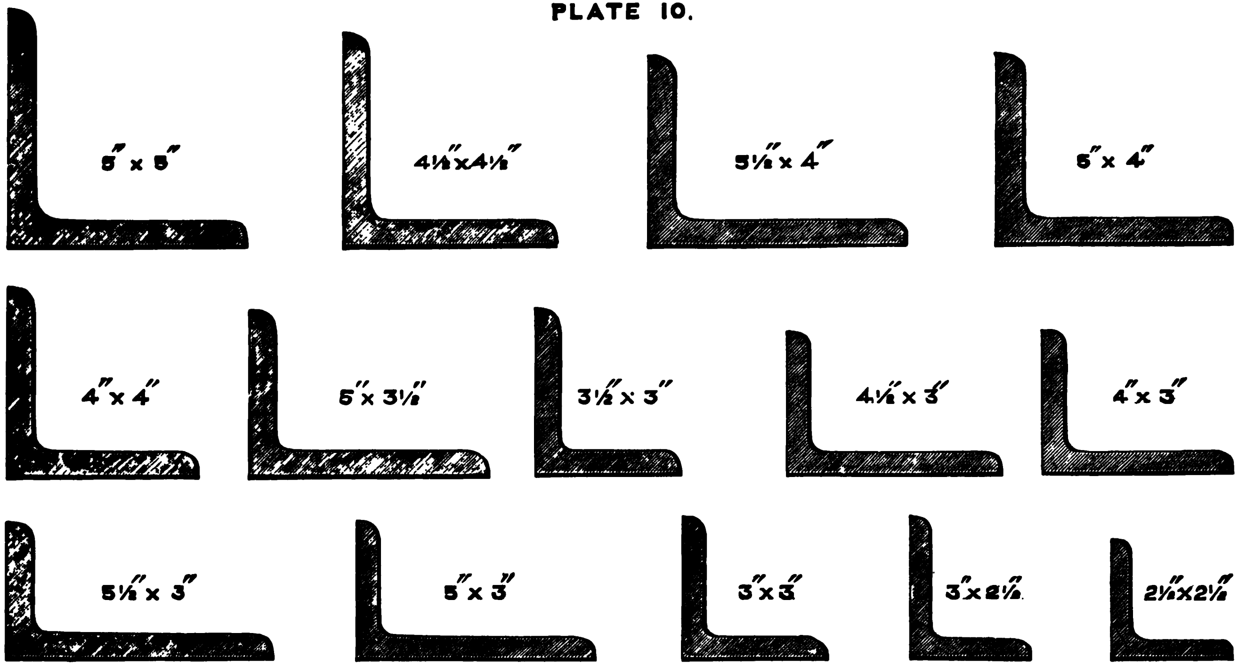


THE THICKNESSES CAN BE VARIED.

SCALE. ¼ FULL SIZE

SECTIONS OF ANGLE IRON, ROLLED BY DORMAN, LONG AND CO., MIDDLESBROUGH.

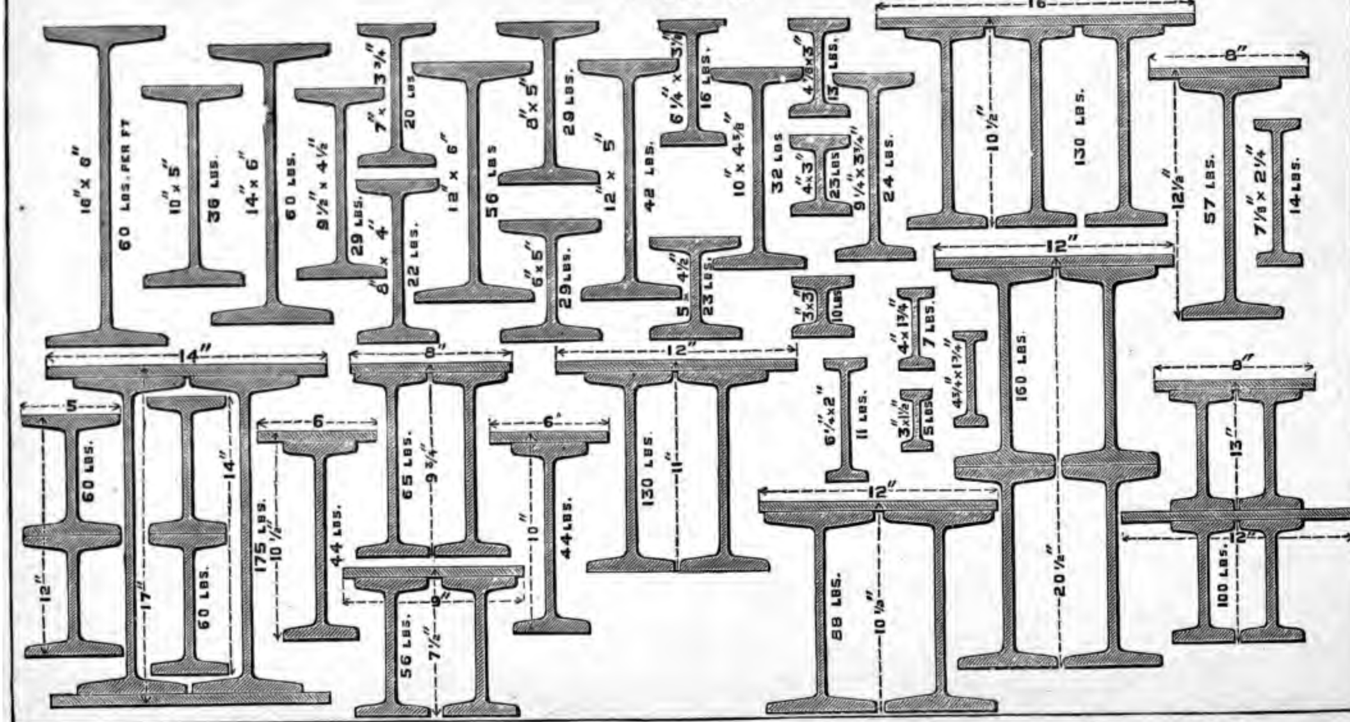
PLATE 10.



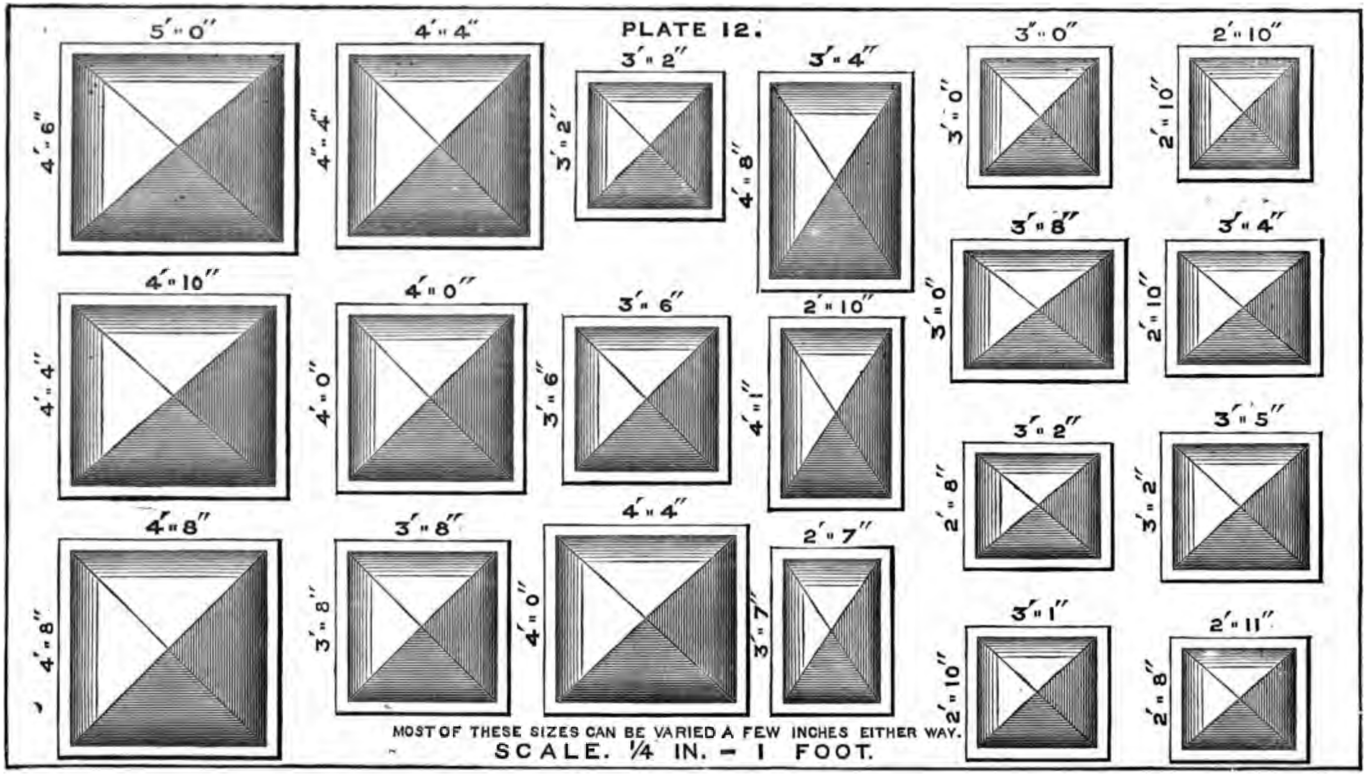
THE THICKNESSES CAN BE VARIED.
SCALE. 1/4 FULL SIZE.

PRINCIPAL SECTIONS OF ANGLE IRON, ROLLED BY THE SKERNE IRONWORKS COMPANY, LIMITED.

PLATE II.



Sections of Rolled Joists and Patent Beams from the List of Measures Brothers and Company, London.



SIZES OF MALLET'S PATENT BUCKLED PLATES MADE BY THE SKERNE IRONWORKS COMPANY, LIMITED.

whether in tension or compression, was required. Secondly, steel plates have not yet been produced at so low a price as compared with those of iron, as has been the case with rails and other bar-like sections. This is chiefly owing to the difficulty in disposing of the large amount of scrap produced in plate-rolling.

Lastly, many engineers maintain that girders so reduced in weight as to make steel compare favourably, in point of cost, with iron, would be lacking in the stability due to the greater weight of material.

On the Continent, steel is much more extensively used in girder construction. This is especially so in the platforms, or bearing girders of bridges of wide span; and there can hardly be a doubt that its adoption in such cases is attended with great advantage and economy.

It should, however, be borne in mind that, so far as present experience tends to show, steel is not more durable—perhaps even somewhat less so—than iron in exposed or damp situations.

No advantage, therefore, would attend its use where the durability of the structure, and not its strength, indicate the thickness or size of any of its parts. This is often the case in the webs of the main and cross girders, flooring plates, &c. &c. where, in point of fact, the very worst iron that is made is often the most suitable, as it has been repeatedly shown that hard, brittle material is far more durable than that of a softer and more ductile nature, whilst the thickness necessary for wear so far exceeds that required for strength, that no fear of failure in this respect need be apprehended.

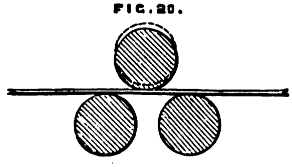
Steel is more suitable for members in tension than for those in compression, and as far as possible bars should be used in preference to plates. All holes in steel should be drilled, and the use of the drift religiously avoided. Fig. 19 shows a piece of steel, or iron of a very steely nature, made by Mr. R. Howson, of Middlesboro', at the Britannia Works. This is understood to be produced entirely from Cleveland iron, and shows to what extent a hard phosphorous containing pig may be used in the manufacture of such material.

FIG. 19.

WORKMANSHIP.

On reaching the girder-yard from the mills, the first process to which the iron is subjected is that of flattening in the case of plates, and straightening in that of the narrower sections of iron. Where the plates are thick enough, the flattening can be accomplished by means of rollers arranged as shown (Fig. 20), the top roll being adjusted in height to suit the thickness of the plate. When the plates are thin, or have been finished in the mills at a low temperature, it is very difficult to flatten them in the rolls; and unless they

FIG. 20.



are annealed, recourse must be had to the somewhat objectionable process of hammering. If, however, they have been carefully managed in the mills, and as far as possible flattened there whilst hot by means of wooden mallets, but little cold hammering will be necessary.

Thin plates, ¼-inch thick and under, are sometimes almost unavoidably damaged in flattening; they should not, therefore, be of large superficial area where narrower plates would answer the purpose equally well.

Bars and angles are also often straightened by means of the hammer, the workmen preferring this to the more tedious process of machine-straightening.

In some cases, especially where the bars are much twisted, the use of the hammer can hardly be dispensed with; but usually a press or rolls will answer the purpose equally well, and they are much less likely to damage the iron or cause unsightly indentations.

The degree of straightness to which the bars, &c. are brought in the first instance, will depend upon how it is proposed to treat them as regards punching or drilling. If the rivet-holes are to be drilled, the bars must be made perfectly straight, but for punched work an approximation to this will do, as the effect of punching a narrow bar is to bend and twist it out of all form, and a second straightening is absolutely necessary.

Whether the rivet-holes are to be punched or drilled, the next process in either case is to mark off their positions. This is now almost universally done by means of templates made of wood or sheet-iron, with holes corresponding in position to those of the rivets bored through them, the marking being done by means of a round peg of wood the size of the hole smeared with paint. A much better plan, however, is to make the template somewhat thicker than usual, and to use a steel punch exactly fitting the holes, which are better if made a good deal less in diameter than the rivet holes, or say about half an inch (Fig. 21). Each "pop" thus represents the positions of a rivet hole.

FIG. 21.

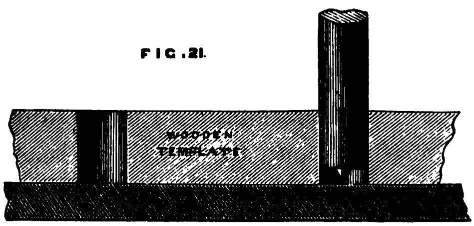
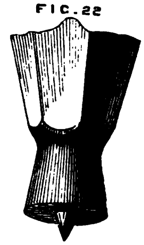


FIG. 22



The punch itself, instead of being flat-ended, has a pointed, central projection (Fig. 22), so that the position of the rivet-hole is assured with much greater accuracy than is practicable with the painted wooden marker.

Blacksmiths' work always adds greatly to the cost of girder construction, and should, for that reason alone, be almost entirely dispensed with. When absolutely necessary, the bars to be smithed should not be thin or very wide in proportion to their thickness. They should also be of a somewhat better quality of iron than would otherwise be necessary. Welding is almost always avoided in carefully-designed girder-work.

It is impossible, under any circumstances, that a weld is perfectly sound, or that a bar is equally strong at a weld as elsewhere.

"Cranking," bending, and "joggling" stiffeners (Fig. 23) is generally done by hand labour, but a more

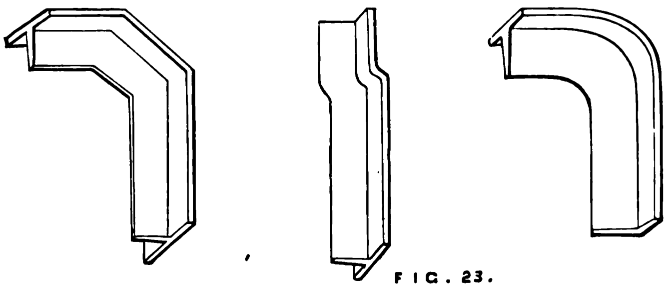


FIG. 23.

uniform result may often be attained, and much expense saved, by the use of the press. It is almost impossible to avoid damaging, more or less, a rolled bar of angle or tee iron in the operations of cranking and joggling, and, as already observed, the difficulty is much greater where the iron is of thin section. Tee iron is more easily managed than angle iron.

Not unfrequently specifications require the whole of the rivet-holes to be accurately drilled to gauges, and with such nicety that the inspecting engineer finds it impracticable to insist upon the letter of the specification being adhered to, and very often punched holes are allowed where drilled holes are specified. Some engineers, in fact, are of opinion that drilled is little, if at all, superior to punched work, but probably some misconception exists on this point.

It is true that the result of many experiments tend to show that punching does not injure the iron to such an extent as might be supposed, the fibre being apparently disturbed but for a short distance—about $\frac{1}{16}$ of an inch, it is said, from the surface of the punched hole; and it has been found that a plate or bar with holes punched through it, or a riveted joint in which the holes had been punched, shows but little signs of weakness beyond what is due to the diminution of sectional area.

From these facts it has been argued that no benefit can be expected to accrue from the substitution for the punching process by the supposed more expensive one of drilling, and it has been further stated that a punched hole is better than a drilled one, inasmuch as it is necessarily somewhat tapered, and thus answers the purpose, to a certain extent, of a countersunk hole.

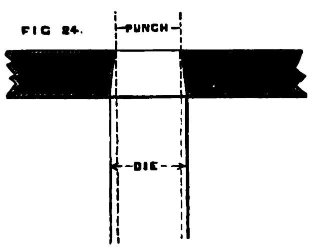
In addition to this it has been found that drilled holes, when each bar or plate has been drilled separately, do not correspond with each other better, or even so well, as when they have been carefully punched; and that whilst any slight inaccuracy can be remedied in the latter case by means of the drift, this instrument cannot be brought to bear with equal effect in the drilled hole.

These arguments, however, do not by any means cover the whole ground. In the first place, the various pieces of iron of which the girder is to be composed should not be marked off and drilled separately, but the whole girder, or if a large one a segment of it, should be strapped together or fastened by a few isolated bolts, and the rivet-holes drilled through all the thicknesses of iron simultaneously. By no other method, whether drilling or punching be adopted, can accuracy be attained.

No punched work, especially, can compare with work so produced; for, however careful or skilful the workman may be, it is beyond his power to punch a series of holes in two long bars, for instance, which shall even approximately correspond.

In the process of punching, it is necessary that the punch be made a little smaller than the corresponding opening in the "die." This difference, of course, depends upon the thickness of the iron to be punched,

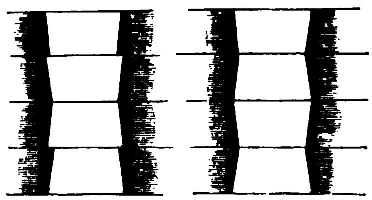
FIG 24.



but may be taken as not much less than ⅛ of an inch to the inch in thickness (Fig. 24).

This difference constantly increases as the work proceeds; *i.e.* the punch wears smaller, and the opening in the "die" becomes larger. The operator does not object to this, as it facilitates his work, and the constant attention of the inspector or foreman is required to prevent the use of punches and dies in which the relative difference in diameter is too great. Assuming, however, that a proper proportion can always be maintained, and, as an example, four plates an inch thick are each punched with an inch hole, and placed in juxtaposition for riveting, they may be placed as at Fig. 25 or Fig. 25 A; in either case the smaller diameter will represent that of the rivet. The larger end of each hole will thus be 1·125 inches in

FIG. 25. FIG. 25 A.



diameter, or, including the space round about in which the fibre of the iron has been disturbed, the diameter will be 1·205 inches.

If these four plates constitute the flange of a girder twenty inches wide, with four rows of rivets as at Fig.

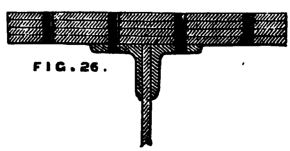


FIG. 26.

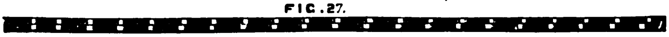
26, it will be found that the excess loss of sectional area due to punching is about 5 per cent. Allowing, however for unavoidable inaccuracies, the enlargement of the holes by rhymering, drifting, &c. this loss may very fairly be doubled.

It may be said that if proper care and skill is exercised the holes will correspond exactly, and no drifting, &c. be necessary; but this is not so. All narrow flat bars, angles, &c. or plates of small sectional area, after having had one or more rows of holes punched in them from end to end, will be found to have become elongated more or less; and if two bars thus punched are placed together for riveting, it will invariably be found that this elongation has not been uniform, the difference depending upon the quality of the iron,—soft iron stretching in the operation of punching much more than that of a harder nature.

This difference will be still greater if a long bar of angle-iron of small section, and a plate of the same length are marked off the same template, and then punched.

It is not uncommon in such cases to find the difference in elongation to amount to as much as the full diameter of a rivet (Fig. 27).

FIG. 27.



In curved work the difficulty will be still greater, and although there are various expedients for obviating it to some extent, it is impossible to do so entirely; and it would be almost too much to expect to avoid entirely holes as much as $\frac{1}{4}$, or even $\frac{3}{8}$, of an inch out of position, unless the bars are extremely short or wide in proportion to the size of rivets, or the conditions are otherwise exceptionally favourable.

So far, the evils inseparable from punching cause only a moderate loss of actual strength in some such substantial member of a girder as the main flange.

In such a case the loss is easily allowed for, and may fairly be considered not to exceed certain limits with good workmanship.

They are, however, far greater as regards the lighter, though equally important, parts of the structure—the lattice-bracings and ties of various kinds.

In such cases the whole strength of the girder sometimes depends upon that of three or four rivets. Such rivets have often to be forced into holes which they cannot possibly fit, and which may be rendered still more unsuitable to receive them by the slightest mishap or carelessness on the part of the workman.

In practice, the drift, or rhymer, has almost invariably to be used.

The former tool, if tool it can be called, is one of the most barbarous instruments to be found associated with constructive art, and its use should now be as obsolete as that of the bone fish-hook or flint arrowhead of bygone days.

It is made of a soft tough quality of steel, so as to bend a little where necessary, and so follow the tortuous course of a series of ill-corresponding holes.

It has no cutting end or edge, but is simply driven

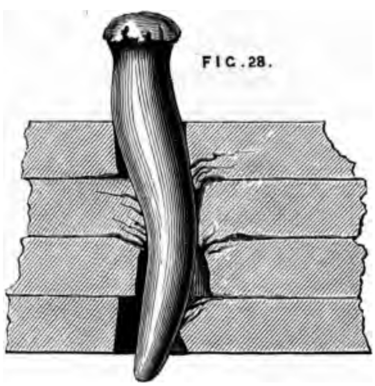
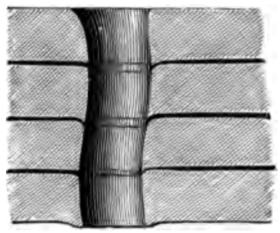


FIG. 28.

in by main force of the hammer--squeezing, bending, and cracking the iron in its relentless course (Fig. 28).

One of the most mischievous effects of the drift is to force the plates, &c. apart by thickening their edges (Fig. 29).

FIG. 29.

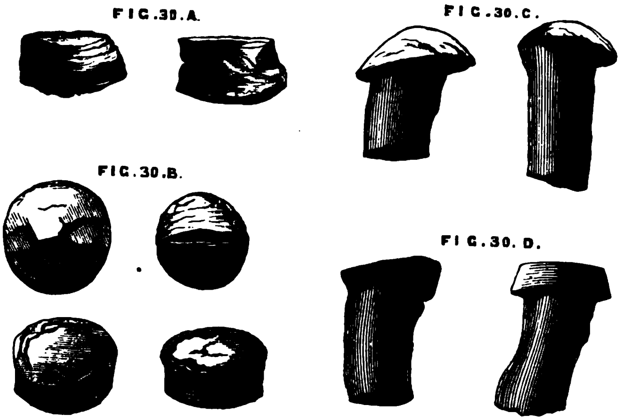


Should it be thought that the illustrations show an exaggerated state of things, it would be interesting to take at random from a scrap heap a piece of old boiler, or other riveted work, and shear it longitudinally through the centre line of rivets. An average sample is represented at Fig. 30. Many, very many, will be much worse than this; as will also any piece of

FIG. 30.

punched girder-work, where three, four, or more plates have been riveted together. Figs. 30 A, 30 B, 30 C, and 30 D (*see* p. 58) show samples of punch-burrs and old rivets. The former are considered to indicate the quality of the iron—more especially its degree of hardness; but good iron will often split as shown when the punch and die are unduly proportioned.

In many cases, in order to get in the required number of rivets in such situations as those of the ends of bracing bars, &c. the holes are necessarily as



close to the edge as the iron will stand in punching without cracking. Under the operation of the drift it cannot be questioned that the material is, in such cases, often stretched far beyond its limits of elasticity, and is, in fact, on the point perhaps of cracking through to the edge, even when such cracks do not show themselves; and it would probably be unsafe to calculate on such a punched connection being in reality more than two-thirds of its theoretical strength.

In endeavouring to obviate these objections to punching by substituting drilling for that purpose, it must be allowed that some special appliances, such as have not yet been worked out or applied, would have to be put into operation.

It has heretofore been usual to drill such portions only as the main booms, in the manner described on page 52, *i.e.* where drilling is the least essential; the holes in the bracing bars, &c. being generally either punched, or, what is little better, drilled separately, requiring, therefore, to be subsequently drifted or rhymered.

It would not be difficult to arrange matters so that every hole could be drilled in position, and that at no great increase in cost after the first outlay for machinery. But supposing this increase to amount to twenty shillings per ton, it would be trifling compared to the increase in actual strength of the girder.

The various component parts of a girder having been "marked off" as described, and the butts and edges of the plates planed true to gauge, the whole should be clamped together for drilling.

In the case of large girders, of course, segments only can be operated upon at one time.

Various forms of multiple-drilling machines have been devised, each with merits of its own. The following are requisite qualities for economical and expeditious work.

Each drill should rise and fall by means of an independent feeding gear.

The pitch of the drills should be readily adjustable in the length of the work, and the whole row of drills should have a cross travelling motion.

Each drill should have an independent disengaging apparatus.

There should not be more than about twenty drills.

As to the last point, the number of drills given is as many as one man can conveniently look after, and two machines with twenty drills each will cost as little, and do more work, than one machine arranged with forty drills.

In the absence, as yet, of any machine so arranged as to drill the connecting holes in bracings, ties, &c. *in situ*, these should either be drilled by hand, or marked off in position, and drilled in the machine; but as either process is tedious and expensive, it should be clearly specified if such a mode of construction is contemplated.

After the holes have been drilled, the various members should be taken apart again, and the "burrs" carefully scraped off, otherwise they will prevent the various pieces coming into perfect contact.

Some engineers also prefer to have each end of the hole countersunk a little.

Work thus prepared can be re-bolted together and riveted up with great rapidity, and there is little or no danger of the iron, after having once passed the straightening or flattening process, suffering damage from rough usage in any way.

It is true that this may open the way to the use of inferior material, *i.e.* iron that will stand drilling will not, necessarily, stand punching, or, still less, drifting. But bad iron should be stopped at the testing machine, and to treat it in such a manner as the very best will only just stand, is radically bad in principle as in practice.

In punched girder-work much greater skill is called for in plating than drilled work requires.

As previously explained, owing to the unequal elongation of the narrower sections and other causes, the various parts have to be fitted together in such a way that the rivet-holes will correspond as nearly as circumstances will allow ; and in order to leave room for a little adjustment in this way, the plates, &c. are almost unavoidably planed a little short, causing open "butts." Unless this is done the ends of the plates have not unfrequently to be re-planed, dressed roughly by hand chipping, or hammered up.

Practically it is impossible to secure close butts in punched work. When the best has been done, unless the holes have been punched much larger than the rivet in the first instance, it will be necessary to drift or rhymer them before the rivets can be got in, and even then it cannot be expected they will, at least in the case of hand-riveting, really fill any but a very short hole.

Some engineers are careful to specify that the rivets are to be heated the whole of their length, and the points cooled a little in water previous to insertion. This, of course, is with a view to the rivets swelling to some extent along the whole of their length, under the action of the hammer, and so filling the holes.

When the holes are, as they necessarily must be in punched work, a good deal larger than the rivets, this precaution is no doubt a useful one, but it may be doubted if it is equally beneficial in the case of straight, parallel, drilled holes.

The rivets being heated to whiteness, expand considerably, and the holes have therefore to be of correspondingly larger diameter to allow them to enter.

In cooling, the rivets contract again, and in a perfectly straight hole bear no where on the surface of the iron except under each head.

It is easier to detect loose rivets in drilled than in punched holes.

In many cases where, owing to the position of the rivets they are difficult to snap, they may with great advantage be substituted by turned bolts driven tightly in.

These may, indeed, be put in anywhere without the least fear of affecting the strength of the girder, as in such situations where skilled riveters cannot be met with.

The Kistna girders (to be afterwards described) were bolted together for testing in their way, no riveting being employed at the connections.

For the sake of appearances, more than anything else, the rivets are usually finished with a cup-shaped snap.

It is well known, however, amongst practical boiler-makers, that rivets so finished are not so tight as those hammered until they are nearly cold, and finished off without the use of the snap.

No hand-riveting can compare with that done by machinery, hydraulic or otherwise.

A powerful press will squeeze a rivet at almost any temperature so as to fill a very rough and unshapely hole; and whilst a mechanic will undertake to cut out hand-snapped rivets at the same price per hundred as that charged for putting them in, he will want two or three times as much to remove those put in by the press.

Unfortunately, the machine is almost inapplicable where its want is most felt, *i.e.* in riveting up the connections, &c., and in practice the machine is only used for plain work, and on tolerably light and handy girders.

Portable riveting machines have been applied in some cases, but are under many conditions of difficult, if not of almost impossible, application.

Loose rivets may easily be detected by tapping, and many seemingly tight ones may be tapped until they become loose.

Perfection in this respect should not be looked for. It is a complicated question of contraction and expansion, and so long as "hot riveting" is adopted, there will always be a certain proportion of loose rivets, and, one still larger, of rivets on the point of becoming so.

Really loose rivets should, however, be at once replaced, and no attempt on the part of the workmen to fasten them by hammering permitted.

Oiling the iron with a view to prevent its oxydation may be done either whilst it is cooling after leaving the rolling-mill, or when it is cold.

Probably the best mode is to postpone the operation until the work is ready to put together for riveting.

But in this case if the iron has been so long exposed to the weather as to be in a rusty condition, it should be well scraped before oiling, and either warmed or washed in a weak acid solution, so as to have a perfectly clean surface. When oiled hot in the mill the iron is very apt to scale, and all good effect of the oiling is thereby lost.

In the case, however, of thin plates, which cannot be brought down to the specified thickness before the temperature has become reduced below the scalingpoint, oiling in the mill may be practised with a greater degree of certainty as to results.

Some remarks have already been made as to the relation the different forms of rolled iron girders bear to the cost of riveting.

It is proposed to follow this question a little further, and to consider the question of cost as affected by general design as well as by the class of material used in construction.

The bulk of material in a proposed girder having been reduced by the engineer to a minimum quantity consistent with its required strength and stability, the three chief points to be considered with a view to economical construction are—how smith-work may be avoided, riveting dispensed with, and angle iron and flats of medium sizes be used to the exclusion of plates, tees, or unusual sections of any kind.

All other questions, with the exception of that of drilling or punching, already considered, are of minor importance, as the exclusion of smithed work may be understood to imply a certain simplicity and uniformity in the design of the girder.

The cost of the materials of which a girder is to be composed may vary ten per cent. or more, according to the sections used.

The smith-work may run from nothing up to twenty or twenty-five shillings per ton, and the riveting from, say two shillings and sixpence up to twenty shillings per ton. To take a rather extreme case, a girder designed in an expensive way might cost, say, twenty-five per cent. more than one of equal strength but more economical design.

Taking £10 per ton as the standard price of plate iron, the following estimates may be supposed to represent the two extremes :—

A Cheap Girder.

	£	s.	d.
Angles, flats, &c. 98 per cent. @ £9	8	16	5
Rivets, &c. 2 ,, @ £12	0	4	9
	£9	1	2
Waste, 5 per cent.	0	9	0
Plating	1	10	0
Riveting	0	2	6
Painting	0	5	0
Tools, stores, and general charges, say	2	5	0
	£13	12	8

An Expensive Girder.

	£	s.	d.
Plates, tees, &c. 80 per cent. @ £10	8	0	0
Angles ... 10 ,, @ £9	0	18	0
Rivets ... 10 ,, @ £12	1	4	0
	£10	2	0
Waste, 5 per cent.	0	10	0
Plating	2	10	0
Riveting	1	0	0
Painting	0	5	0
Tools, stores, and general charges	2	10	0
	£16	17	0

A girder is frequently rendered much more costly than it need be, and the time necessary for its construction much increased, by the introduction into the design of a multiplicity of sections, and too great a variety in the forms into which it is worked.

Iron cannot be obtained at current prices, or in a short time in very small parcels: and sometimes it is impossible to obtain even such as makers advertise in their section sheets, except the commonest sections, at a reasonable price, or with any guarantee as to delivery, unless the quantity is such that it will pay the maker to put in the rolls for the section required.

The *thickness* merely of the iron may be varied at will in the case of all flats, mostly so in that of angle-iron, and to some extent also as regards tees and other sections; and wherever practicable, the sectional area of struts, ties, &c. should be varied by reducing or increasing the thickness only, and not the width or length of side.

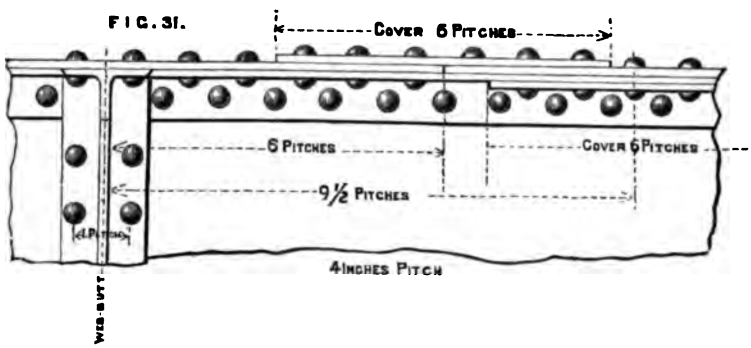
Much labour and expense may also be saved to the contractor by the engineer, if care is exercised in fixing the lengths of plates, bars, &c. which should always be divisible by the standard pitch of rivets. It is a good plan, indeed, to use the rivet-pitch as the unit of length throughout, and all covers, connections, stiffeners, &c. should be so designed as to interfere as little as possible with the standard pitch, as all irregular riveting increases the cost of girder-work (Fig. 31).

Many engineers are careful in designing girders so to arrange the various members as to "break joint," that is, that the butts of the main angles in the flanges do not coincide with those of the plates, nor these last one with another.

This point, again, is disregarded by other engineers as a totally unimportant one: and for the sake of making a girder in uniform, compact lengths, all the members are made to terminate together at what is called a "full butt."

The question is one for the professional engineer to decide, and beyond the scope of this work; but

FIG. 31.



supposing there to be no objection to "full butts," they are much to be preferred to broken joints.

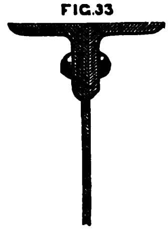
The Kistna girders, of which mention has already been made, were constructed in this manner, the various lengths being riveted up complete, and then faced at the ends in a planing machine at such an angle as to give the necessary camber (Fig. 32).

FIG. 32.

By this means the segments of the main booms were fitted together with a degree of accuracy unattainable on the broken joint system, where really close butts are almost impossible.

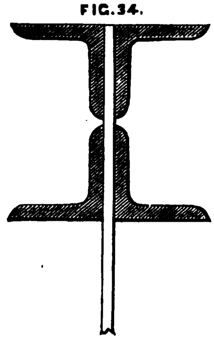
There is also another advantage attending the use of full butts. There are no awkwardly projecting plates or bars likely to be bent or damaged during transport—a not unimportant consideration where the girders are to be exported, frequently transhipped, or conveyed a long distance by sea or land

FIG. 33



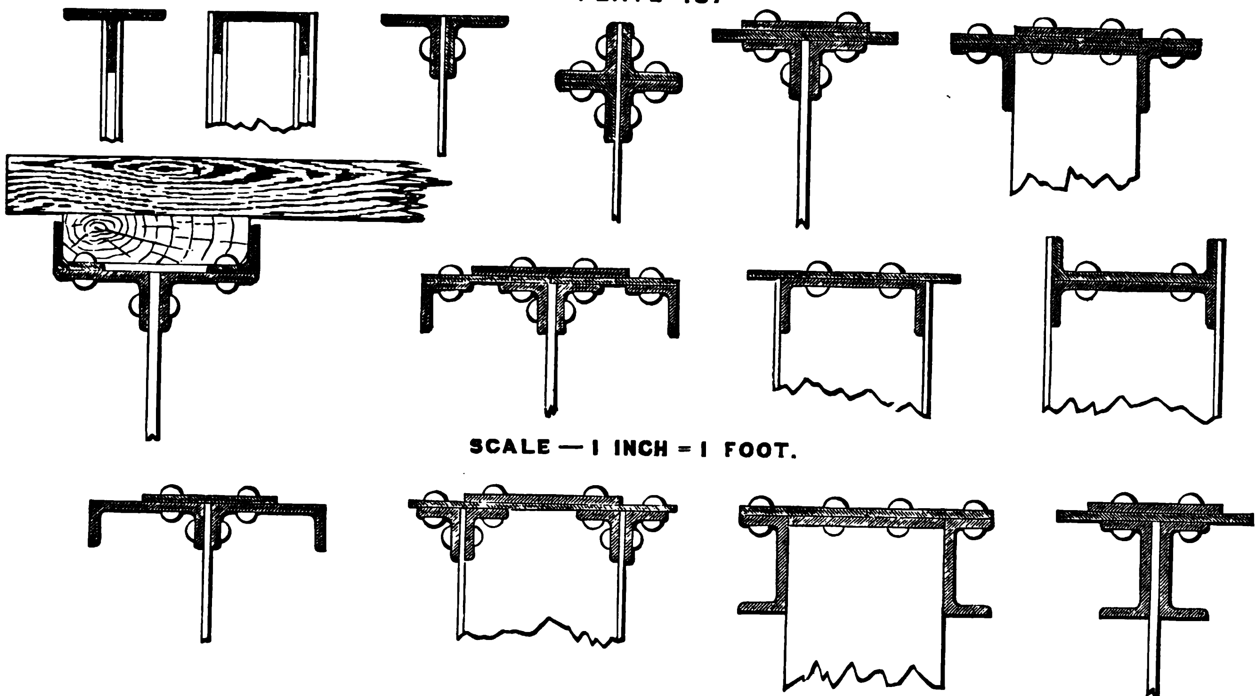
Within certain limits as to length of span, the most economical section for a main compression-member, or top boom of a straight girder, is that composed of two bars of angle-iron with a plate between them (Fig. 33).

FIG. 34.



When a greater sectional area than four or five inc
is required, it is usual to adopt one or more fla

PLATE 13.

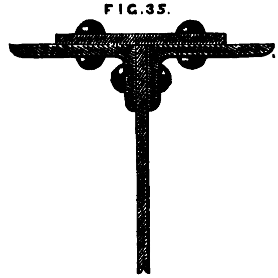


SOME SECTIONS OF FLANGES OF GIRDERS COMPOSED OF BAR IRON OF VARIOUS SECTIONS

plates, according to the strength required. A more economical section, however, is that used by the engineer of the Indian State Railways (Fig. 34), where the top and bottom flanges of girders, up to 130 feet span, are composed almost entirely of angle-iron, with but very little riveting.

Should a greater degree of lateral stiffness be thought necessary, the angles could be made unequal-sided without increase of cost up to nine or ten united inches. When even a heavier section is required, the use of plates may still be avoided by an arrangement similar to that shown in Fig. 35, the top connecting-

FIG. 35.



piece being a bar eight inches wide or under. In booms of almost any strength, the use of plates may be limited to one in width, or even entirely dispensed with.

Plate 13 shows various sections composed of angles and flat bars only.

These sections, it is clear, might be varied almost indefinitely to suit particular circumstances, and they are introduced simply in order to show how the stereotyped form of plate and angle-iron boom may be advantageously modified in the pursuit of strict economy.

Narrow plates, especially long, narrow, thin plates, such as often form the flanges of small girders, cross flooring beams, &c. are the *bête noire* of the plate-roller, who dislikes them almost as much as plates of great width; and although no difference in price may appear in the trade lists, five or ten shillings per ton more will always be asked for such plates than for those of more desirable dimensions.

The main-tension member, or bottom boom of a girder, is in most cases, unless the girder is of large dimensions, made similar in form to that of the top boom. It may, however, generally be modified with advantage as regards its cost; and here it is still easier to substitute angles or flat bars for plates.

The various forms of bracing, and modes of attaching them to the main booms, are too numerous and well known to need description here.

The labour in construction will be materially affected by their uniformity or otherwise, as regards width, arrangement of rivets, &c. If they can all be of similar pattern, so much the more likely is the workmanship to be sound and good. Repetition, above all things, enables the practical girder-builder to turn out his work to the satisfaction of his customer and profit to himself.

PART II.

EXAMPLES.

The Construction of Wrought Iron Girderwork.

PART II.

EXAMPLES.

IN briefly describing some of the structures in wrought iron of a girder-like character constructed at the Skerne Works, no attempt has been made to classify them under the various heads—" Plate," " Triangulated," " Lattice," &c. Such a classification would seem to be useful only when treating the subject theoretically, and when the various strains incidental to the several members of each kind of girder have to be separately analysed and examined. In practice, the various kinds of girder merge almost imperceptibly one into another, giving rise to many subdivisions, and making it difficult in numerous instances to say to which type they belong.

It is also almost impossible to draw a hard-and-fast line between a bridge and a viaduct, a jetty and a pier, &c. The descriptions, therefore, will be found to have reference to most of the kinds of structure where girders in the sense of beams made of wrought iron are used in no particular order, and without regard to the purposes they are intended to serve.

Most of the works described were carried out more or less strictly in accordance with the designs and specifications supplied by the professional engineers whose names are given. In some cases these designs are so carefully worked out, that the position of every rivet is indicated with great exactness, and no deviation therefrom or modification, however slight, is permitted on the part of the constructor. In others, little more than the strength of each member is given, the constructor being permitted to use such sections of iron as may seem most suitable, or can be most readily obtained. Some of the bridges described were designed entirely at the Skerne Works.

Whilst it is clearly desirable that the engineer's plans should be fully worked out in detail, and as rigidly adhered to as possible by the constructor, a degree of latitude is often of great advantage whether as regards economy in cost of construction or of time: as a certain section of iron may perhaps be promptly available where another is not equally so, and it is not unusual to specify a bar of angle iron, for instance, as having to be of a certain sectional area without defining either its thickness or the length of either of its sides.

The advantage of such a mode of drawing up a specification is of considerable importance in the case of orders from the Colonies or abroad, as in such the time occupied in correspondence referring to modifications in the design, which are not unfrequently imperative, greatly retards the execution of the work.

The writer has not felt himself at liberty to introduce copies of any of the engineers' specifications. Had it been otherwise, no doubt such a feature would have considerably enhanced the value of the work.

Plate 14.—The Kistna Viaduct.

THE KISTNA VIADUCT.

GREAT INDIAN PENINSULA RAILWAY.

The girders for this work were constructed at the Skerne Works in 1870-1, to the designs and specifications of Mr. George Berkley, the consulting engineer for the company.

The girders are of the Warren-type.

A general view of the viaduct is given on Plate 14, and details in Fig. 36.

The total length is 3,852 feet, made up of thirty-six spans of 103 feet each, or measuring from centre to centre of piers 107 feet.

The piers, which were not made at the Skerne Works, are composed, each of two wrought-iron cylinders, ten feet in diameter at the base, and tapering to seven feet in diameter at the top.

The triangulated girders are constructed with a top compression flange of open-box section, connected to horizontal tension bars by diagonal struts and ties, forming nearly equilateral triangles.

Each of the tension members consists of one or more rolled links with swelled ends, whilst the main struts are built up of angles and bars or plates in the usual way. The pins at the intersections are of Bessemer steel.

The plate-iron used throughout in these girders was guaranteed to stand a tensile strain of ten tons to the square inch, without any permanent set, and twenty tons before fracture, stretching one inch in twelve before fracture.

The angle and tee-iron were subjected to severer tests: being required to bear twelve tons before permanent set, and to bear twenty-two tons, and stretch an inch and a quarter in twelve before fracture.

The rolled tension-bars were specified to be of the same quality as the plates, whilst the rivets had to bear eighteen tons strain to the circular inch.

The various portions of the girders were fitted with such accuracy as to be inter-changeable, and any strut, tie, or segment of main flange could be removed from any girder and substituted for a corresponding member in another.

The distances between the connecting pin-holes were spaced off so as to be within $\frac{1}{64}$ of an inch in ten feet of the specified dimensions, the pins and holes themselves being bored and turned respectively so as to be within $\frac{1}{100}$ of an inch of the size given.

To secure such accuracy it was necessary to devise special measuring and gauging apparatus, that in ordinary use being found quite inadequate.

Ten of the spans were fixed together, erected on temporary wooden abutments at the Skerne Works, and bolted together with turned bolts for testing.

Two tons to the running foot, being the specified test weight, was then superimposed in the form of pig-iron, equally distributed.

The Kistna girders, owing to the high tests required, the character of the design, and the great accuracy with which they were required to be made, are of a somewhat expensive type.

The erection, however, would be easily and rapidly

FIG. 36.

carried out, and this would in part compensate for the increased first cost.

The spans were turned out at the rate of three per month, or about fifty tons per week.

The total cost of these girders, delivered free on board, was about £37,600, being at the following rates :—

	£	s.	d.	
Compression beams, cross girders, riveted bracing, struts, &c. ...	13	18	0	per ton.
Rolled eye-links	16	0	0	,,
Steel pins	1	15	0	per cwt.
Rollers	1	5	0	,,
All cast iron...	0	11	6	,,

All delivered at Liverpool.

MURRUMBIGEE BRIDGE, AT HAY, AUSTRALIA.

A swing road bridge of four openings; *i.e.* two fixed spans of sixty feet each, and two equal opening spans of sixty-one feet each.

The centre swing pier is a cylinder of wrought iron twelve feet in diameter, filled with concrete.

It is twenty-seven feet in height from ground level to underside of main girders.

The two side piers are formed of two cylinders, also of wrought iron, five feet in diameter each, braced together at fourteen feet centres.

The main girders, of which there are five in the swing-spans, are constructed to a great extent of channel iron.

They are six feet four inches in depth, and two feet six inches apart, centre to centre.

The footways are carried by cantilever-brackets of forged tee iron.

The swing girders ride upon rollers connected by a live ring in turn-table fashion, and are moved by means of hand gearing only. A general view of the Murrumbigee Bridge is given in Plate 15.

The work was carried out under the inspection of Mr. John Fowler, C.E., to a design prepared in the colony. The erection did not form part of the contract.

Owing to the quantity of smithed work in the main and cross bracing, &c. the girders of this bridge are of a somewhat expensive class. With plates at £8 15s. per ton, they cost free on board in the Thames £15 14s. per ton.

MONTESA BRIDGE.

ALMANZA, VALENCIA, AND TARRAGONA RAILWAY, SPAIN.

A view of this bridge is given at Plate 16. It consists of two spans, supported by a middle pier, composed of cast iron columns with wrought iron bracing.

The railway is carried on the top of the girders by a platform of cross-girders of H section.

The girders are of the lattice description, the diagonals being all flat bars of varied thickness, and the vertical stiffeners of tee section.

Strictly speaking, no plates are used in the structure, and in other respects the design is very favourable to economy in construction.

PLATE 15. — MURRUMBIGEE BRIDGE, AT HAY, AUSTRALIA.

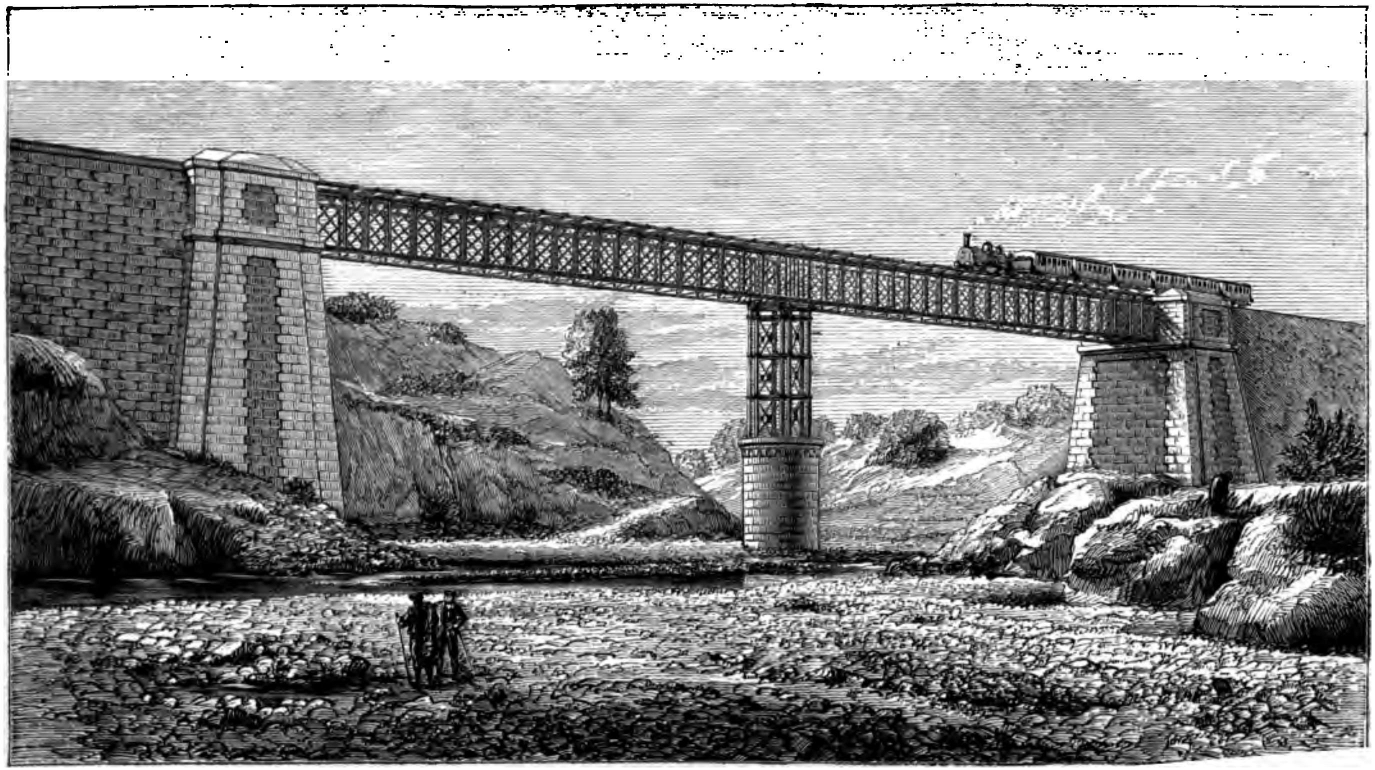


PLATE 16.—MONTE…

The whole of the ironwork, including the pier, was prepared and despatched from the Skerne Works in about five weeks from date of order.

BRIDGE OVER THE RIVER AIRE.

The whole of the wrought-iron bridges on the York and Doncaster section of the North-Eastern Railway were constructed at the Skerne Works.

The designs and specifications were by Mr. T. E. Harrison, C.E., the company's engineer; and the works were carried out under the personal supervision of the late Mr. R. Hodgson, C.E.

The Aire Bridge consists of two unequal spans, supported in the middle of the river by a pier, consisting of two cylinders of cast iron, filled with Portland cement concrete up to the splay length, *i.e.* to about water-mark.

Above the splay length the cylinders are filled with brickwork in cement, and the girders rest on two granite blocks about six feet square each; a piece of sheet lead, 12 lbs. to the foot, being inserted between the stone and the girder bed-plate.

The main girders are of the straight flange plate web kind, carrying cross girders every five feet, between which run short girders carrying longitudinal Memel sleepers.

The curved deck plates are also riveted to these girders.

The whole of the iron used in the manufacture of these bridges was specified to be of Staffordshire scrap quality; but, in lieu of it, the engineer permitted the use of Cleveland iron standing the required test, *i.e.* twenty tons to the square inch without fracture.

The specification states that, "Wherever practicable, the rivet holes are in all cases to be drilled through the entire thickness of plates, angle iron and covering plates, in order that the holes may be perfectly true with each other."

This clause was strictly observed, and as the girders were of most massive design, the result was a rigidity rarely attained in girders of equal span.

Owing to the length of span, it was necessary to build the girders on staging and rivet them up *in situ;* when, however, the staging was removed, no perceptible deflection took place.

A girder drilled in this way may, in fact, be made with a third or a quarter of the camber usually given in the case of punched work, without any fear of its deflecting, even under the rolling load, below the horizontal line.

The other bridges on this line, with the exception of that over the Ouse, near York, elsewhere described, do not merit special reference, being much the same type as that over the Aire.

They consist principally of the Knottingly and Goole Canal Bridge (Fig. 39), with a clear span of 135 feet; the Selby Canal Bridge (Fig. 41); and a series of road bridges at Selby Junction.

There are, besides, several smaller road bridges, with floorings mostly of Mallet's buckled plates. All the bridges on this line have single-plate web main girders,—a rather peculiar feature, as few engineers adopt this form in the construction of bridges of such

Plate 16 a. — Aire Bridge.

a span as that of the Selby Canal Bridge, much less in those of greater length. They are not to be taken as examples of economical construction, either in point

FIG. 39.

of material (quantity or quality), or workmanship; but for solidity, durability, and strength, they could hardly be surpassed.

FIG. 41.

A general view of the Aire Bridge is given on Plate 16A, and a section of one of the main girders at the pier, with a portion of the flooring, in Fig. 37.

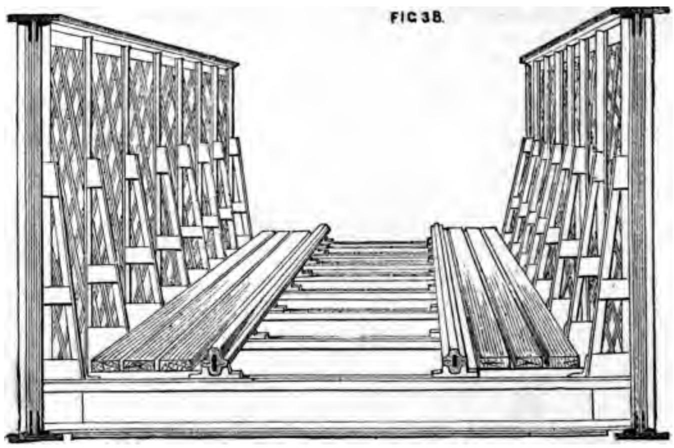
BOQUILLA BRIDGE.

ALMANZA, VALENCIA, AND TARRAGONA RAILWAY, SPAIN.

The superstructure for this bridge (Fig. 38) was twice constructed at the Skerne Works, the first erection having been destroyed during the Carlist war. The second bridge was supplied in four weeks from date of order.

The girders are of a rather close lattice kind, and of extremely simple construction. The cross-flooring girders rest on the bottom flange.

FIG 38.



There are no longitudinal bearing girders, but the working rail being riveted to an inverted one of the same section resting in cast-iron shoes, forms a sort of continuous bearing girder, which seems to be thought serviceable enough.

There is no flooring between the rails, but a planked footway on each side.

FIG. 37.

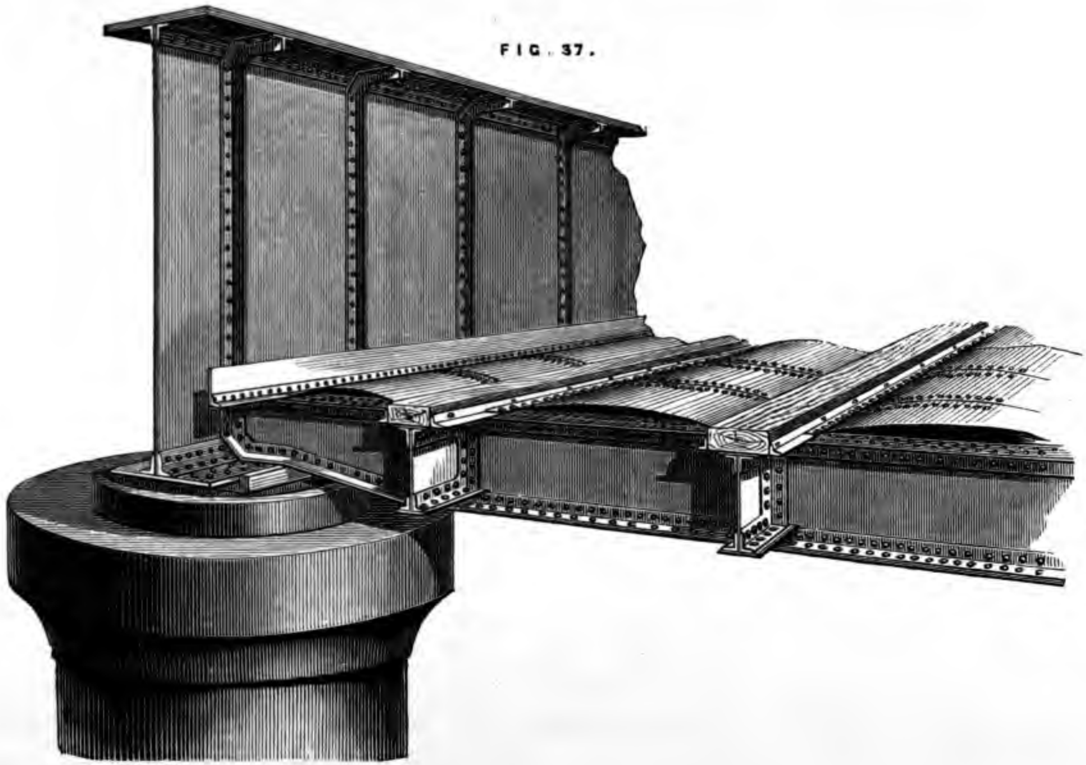


Plate 17. — Bridge over the River Devon.

The bridge is for a single line of rails of the five feet gauge.

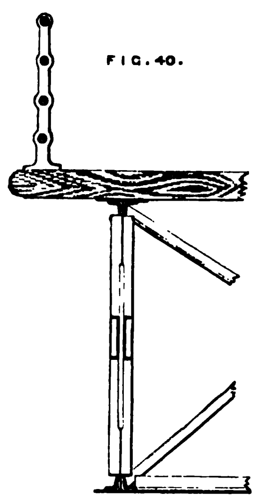
The only test for the iron throughout was one of twenty tons to the square inch ; no variation exceeding a millimetre in thickness of plates &c. was allowed.

BRIDGE OVER THE RIVER DEVON.

DEVON VALLEY BRANCH OF THE NORTH BRITISH RAILWAY.

This bridge, or viaduct (Plate 17), carries the Devon Valley Railway at a considerable height over the River Devon near Dollar.

FIG. 40.



The piers are of masonry. The superstructure, for a single line of rails, is formed of two main lattice girders braced together, a wooden platform, and iron hand-railing (Fig. 40).

There are no cross girders, the timber platform, seven inches thick, being made to do duty instead. The bridge, therefore, so far as the superstructure is concerned, is an extremely cheap one.

With the exception of a fifteen inch strip forming the webs of the top and bottom booms, and the flanges of the same, no plates are used in the construction of the girders. The bracing is of channel iron, and the cross ties of light tee section.

This bridge, depending as it does upon the strength of the timber-floor for lateral stiffness, may possibly require somewhat more than customary attention, as the woodwork decays; otherwise the design, as already stated, is a very economical one.

The total cost, including timber and erection, was £2,982, being at the rate of about £15 6s. per ton for the wrought-iron work.

BRIDGES FOR THE STATE RAILWAYS OF DENMARK.

A series of forty bridges and viaducts of various types, the most important being one of 110 feet span,

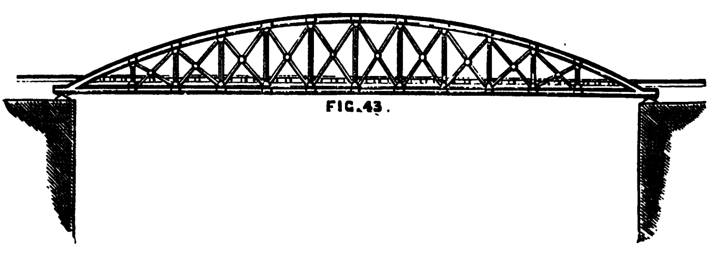


FIG. 43.

and three of two spans, each of 77 feet clear (*v* Figs. 42 and 43).

The form of these girders necessarily implies a great deal of labour and care in construction, more so, probably, than will be compensated for by any saving in material due to the adoption of the bow-string type.

The iron was subjected to a test of twenty-one tons in the direction of the fibre, and guaranteed to be equal to that ill-defined quality, "good Staffordshire."

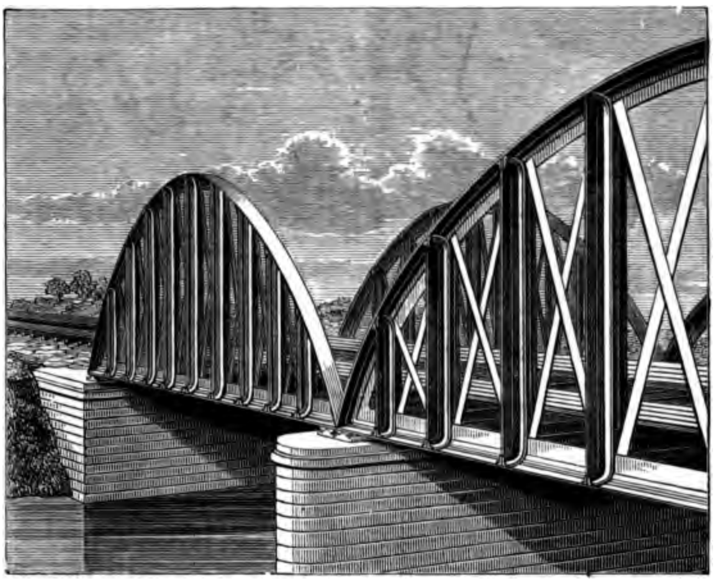


FIG. 42.—BRIDGE OVER THE SKJERN.

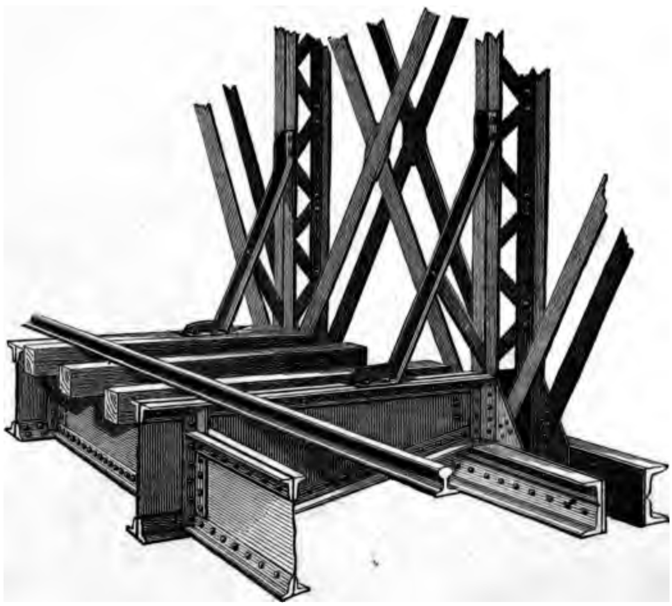
The longer girders were despatched from the works in segments, to be connected at site.

The mode of connecting main and cross girders, rail bearers, &c. is shown in Fig. 44, and the bearing plates in Figs. 45, 45 A.

The lower flange or main tie of these girders is of simple section, and one to which the bracing attachments, &c. are easily made.

With materials, *i.e.* plates, angles, &c. at £10 10s.

FIG. 44.



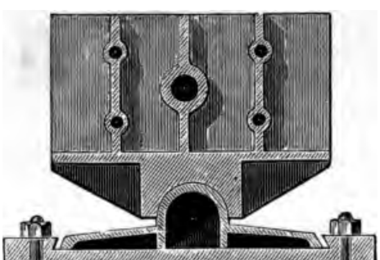


FIG. 45.

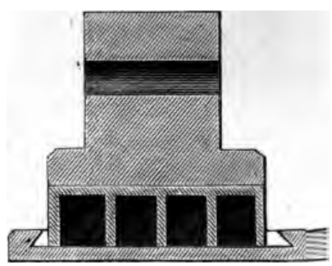


FIG. 45.A.

all round, the price of the wrought ironwork for these girders was £22 per ton, free on board at Hull.

THE BRIDGE OVER THE RIVER TEES AT BARNARD CASTLE.

This is a small foot-bridge of three spans, as shown at Fig. 46, constructed to the design of Messrs. Robinson and Ianson, civil engineers, of Darlington.

The River Tees at this point has been aptly described by Sir Walter Scott, in "Rokeby":

> "Where Tees full many a fathom low,
> Wears with his rage no common foe;
> Nor pebbly bank nor sand-bed here,
> Nor clay mound checks his fierce career,
> Condemn'd to mine a channel'd way
> O'er solid sheets of marble grey."

FIG. 46.

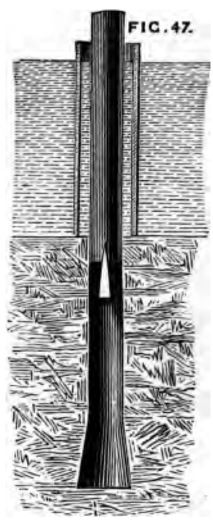
The piers are made of round bar-iron let into the rock, and were fixed in the following manner:—

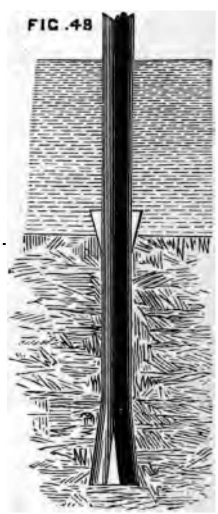
The overlaying gravel having been cleared away, a hole somewhat larger than the leg of the pier was drilled into the rock, and widened out considerably at the bottom.

The leg of the pier was then cut open, and the thin end of a wedge inserted, as shown at Figs. 47 and 48. Heated to a white heat, the bar was then inserted into the hole, guided by a short length of cast-iron pipe, and driven home before it had time to cool; the whole operation lasting, of course, only a few minutes.

Nothing more was necessary than to drive in a few small wedges in order to steady and adjust the pier. The work was all done under water.

The pier legs are braced by means of a solid web, the object being to prevent trees, or other floating *débris*, becoming entangled in the piers in time of flood.





The piers are provided with a cutting edge up stream, so as to offer no impediment to drifting ice, which often accumulates in large quantities just above the bridge. This is an example of very cheap construction.

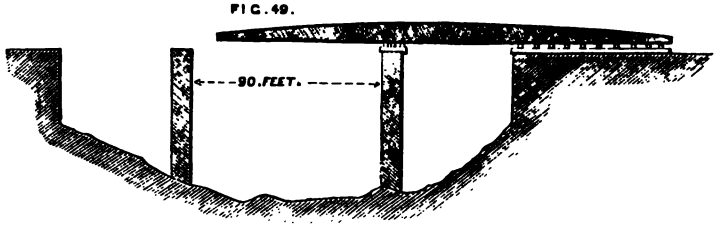
PLATE 18.—GRANDTULLY Rnir

GRANDTULLY BRIDGE.

A small road bridge over the Tay, near Aberfeldy (Plate 18). Owing to the height of the piers and nature of the stream, it would have been expensive and difficult to erect staging upon which to rivet up the main girders, whilst they were too long to swing across by means of cranes or lifting tackle.

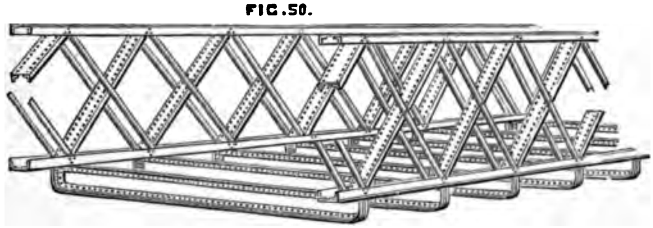
They were, therefore, temporarily attached together and launched, as shown at Fig. 49—an operation which

FIG. 49.



had to be performed with some care, in order to prevent the girders being unduly strained. They are of very light design, and to span the middle ninety-feet opening, had to be heavily counterweighted.

FIG. 50.



Details of the main girders, &c. are shown at Fig. 50. Owing to the arched form of the top boom, and other features which it is unnecessary to particularise, these girders are of an expensive type, and one not likely to be frequently adopted.

The flooring is of timber. The total cost of the ironwork was £502 10s., or at the rate of £15 per ton erected complete.

BRIDGE OVER THE TWEED AT ABBOTSFORD, NORTH BRITISH RAILWAY.

This bridge (Plate 19) replaces an old wooden structure carrying the Selkirk branch of the North

PLATE 19.—ABBOTSFORD.

British Railway across the Tweed near its junction with the Ettrick.

The work was carried out to the design and under the supervision of Mr. J. Bell, C.E., the railway company's engineer. There are seven spans. The main girders have a curved upper flange, the cross girders resting on the lower one and riveted to the main web.

It may be questioned whether any advantage attends the use of the curved upper flange in spans of this length, the increased cost in labour probably reducing to nil any advantage gained by saving in weight.

The girders were sent to the site in segments, and riveted up there.

The piers are of masonry, and the flooring of the bridge is of timber.

The total cost of the ironwork in this bridge was £2,888, or at the rate of £15 11s. per ton erected, the cost of plates at the time being £7 5s. per ton.

VIADUCTS ON THE WHITBY, REDCAR, AND MIDDLESBRO' UNION RAILWAY.

This railway, connecting the Whitby branch of the North-Eastern Railway with the same company's line near Saltburn, runs northward from Whitby near to, and in a line almost parallel with, the coast, crossing at a considerable elevation a number of ravines, varying in width from about three hundred to a thousand feet. A series of viaducts for the purpose of carrying the railway, single line, across the ravines were designed for the company by Mr. John Dixon, C.E., of London. They were constructed at the Skerne Works, and subsequently erected by the company under that gentleman's supervision.

The most important are the Staithes Viaduct, in spans of 60 feet and 30 feet each (Fig. 51); the Upgang Viaduct (Fig. 52), four spans of 60 feet each, and two spans of 30 feet each; the Newholm Viaduct

(Fig. 53), fourteen spans of 30 feet each; the Sandsend Viaduct (Fig. 54), a number of spans of 30 feet each; and the Eastrow Viaduct in spans of 60 feet each.

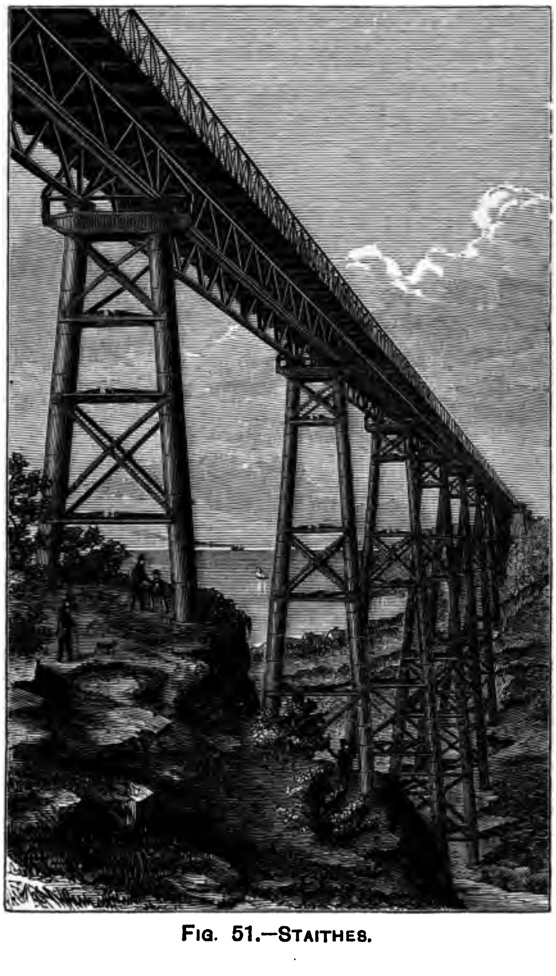


FIG. 51.—STAITHES.

All the 30 feet spans are of the plate, and all 60 feet spans of the lattice, type.

The peculiar feature in the design of these structures is the form of pier adopted. Each pier is composed

FIG. 52.—UPGANG.

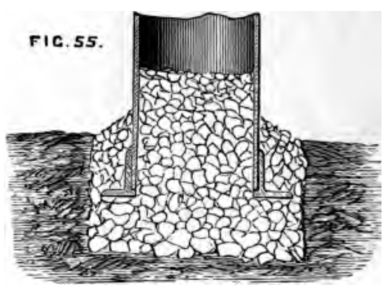
FIG. 53.—NEWHOLM.

of two tubular legs made of plate iron, and braced together at intervals, the interior being filled with concrete. A cast-iron flange standing upon a bed of concrete forms the only foundation for the piers (Fig. 55). For the 30 feet spans the tubes are

FIG. 54.—SANDSEND.

2 feet 6 inches in diameter, and $\frac{5}{16}$ of an inch thick throughout, except the top and bottom plates, which are $\frac{3}{8}$ of an inch in thickness.

FIG. 55.



The upper portions of the piers for the 60 feet spans are also of the same diameter and thickness, but in the higher piers the tubes splay out at intervals, reaching a diameter of 4 feet 6 inches at the bottom of the highest piers.

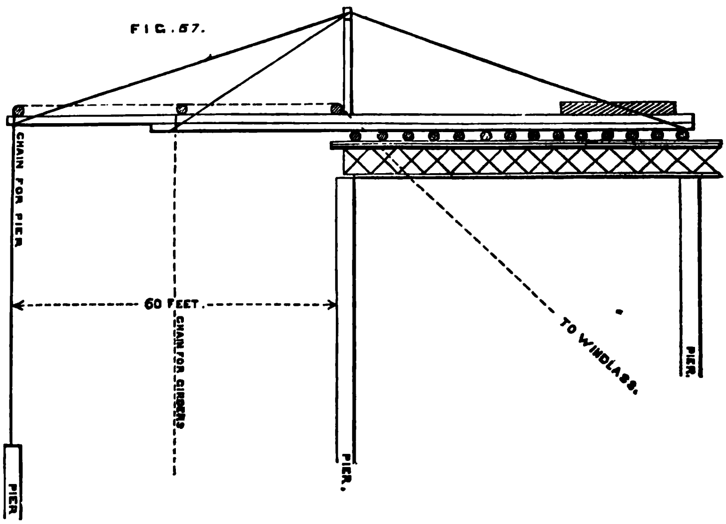
Some of those in the Staithes Viaduct reach a height of nearly 200 feet.

FIG. 56.

Fig. 56 shows the top of one of the piers, with a portion of the main girder, attachments, bracing, &c. A cast-iron bed-plate is interposed between the concrete and the main girders; the outer shell of the tube does not support any part of the dead weight.

Mr. Dixon claims for his invention the merit of being the cheapest form of pier yet introduced, where the height is great and other conditions favourable.

FIG. 57.



The concrete is composed of four parts gravel to one of Portland cement; and the ultimate stability of the piers will, no doubt, in a great measure depend upon the respective qualities of these materials.

The 30 feet plate girders are of the usual section.

The 60 feet girders have a top and bottom flange of angle and plate iron, and double triangular bracings of angle iron.

The cross girders are formed of single bars of angle iron of heavy section, and the flooring is of wood planking laid longitudinally. The mode of erecting the piers, &c. is shown in Plate 20, and at Fig. 57 is

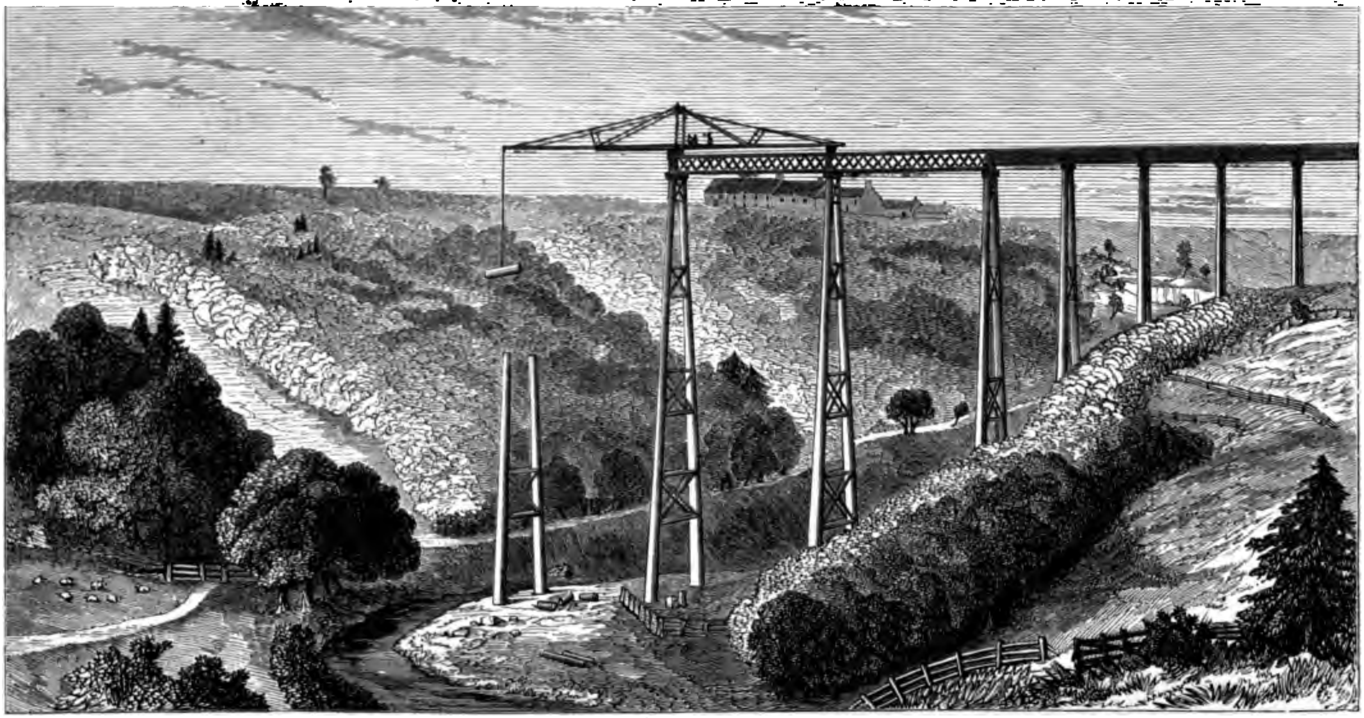


Plate 20.—Staithes.

shown an outline of the crane, or projecting staging from which they were built. The lifting was done by steam power.

By means of this arrangement, the cost of erecting these viaducts was not so great per ton as might have been expected from their great height, &c.; and in situations of a more favourable character as regards materials for making concrete, they would compare still more advantageously in point of economy with either piers of solid masonry or with any of the usual forms of pier in cast or wrought iron.

BRIDGES FOR THE BERGSLAGERNAS RAILWAY, SWEDEN.

A series of twenty bridges, the girders, &c. for which were made at the Skerne Works in 1874.

Most of the girders are of the ordinary plate kind, supported on cast iron column piers (Fig. 58). That over the Daglöselfven has two swing openings, as shown at Plate 21.

The test for the plate iron entering into the construction of these girders was 20 tons per square inch, with an elongation of 10 per cent. That for the angle, tee, and other rolled iron, 22 tons with 12½ per cent. elongation; the rivets capable of being bent double.

For the cast iron, a bar, 3 feet 6 inches long, 2 inches deep, and 1 inch broad, placed on supports 3 feet apart, had to bear a load of 30 cwt. in the centre before breaking, with a deflection of a quarter of an inch.

The testing was conducted by Mr. D. Kirkaldy, at his well-known experimental works in London.

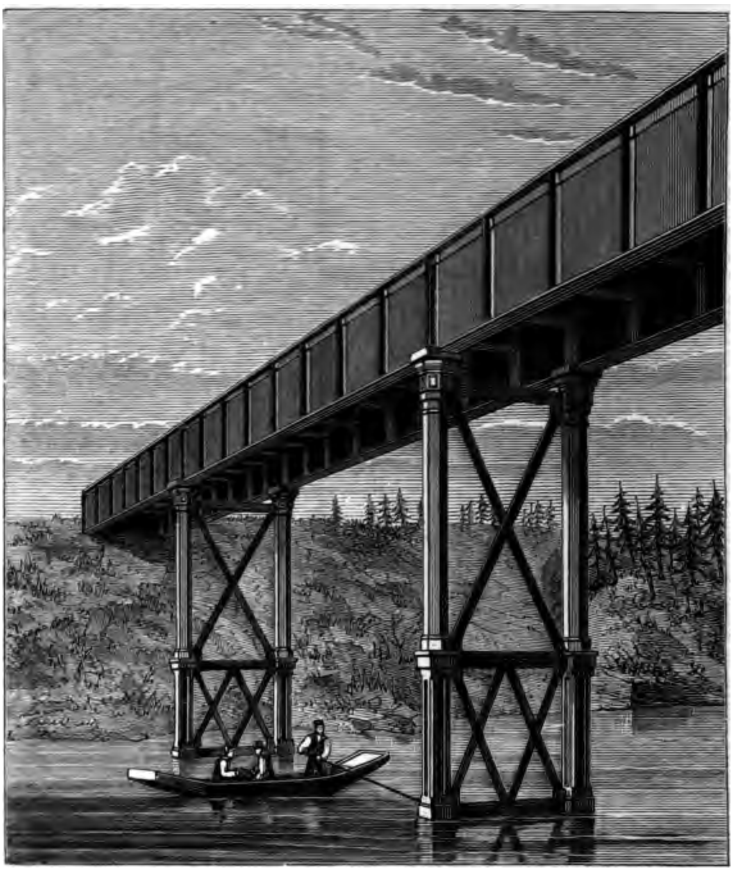


Fig. 58.

In the Daglöselfven bridge there are two fixed spans, and two swing openings of 40 feet each, carrying a single line of rails of the ordinary gauge.

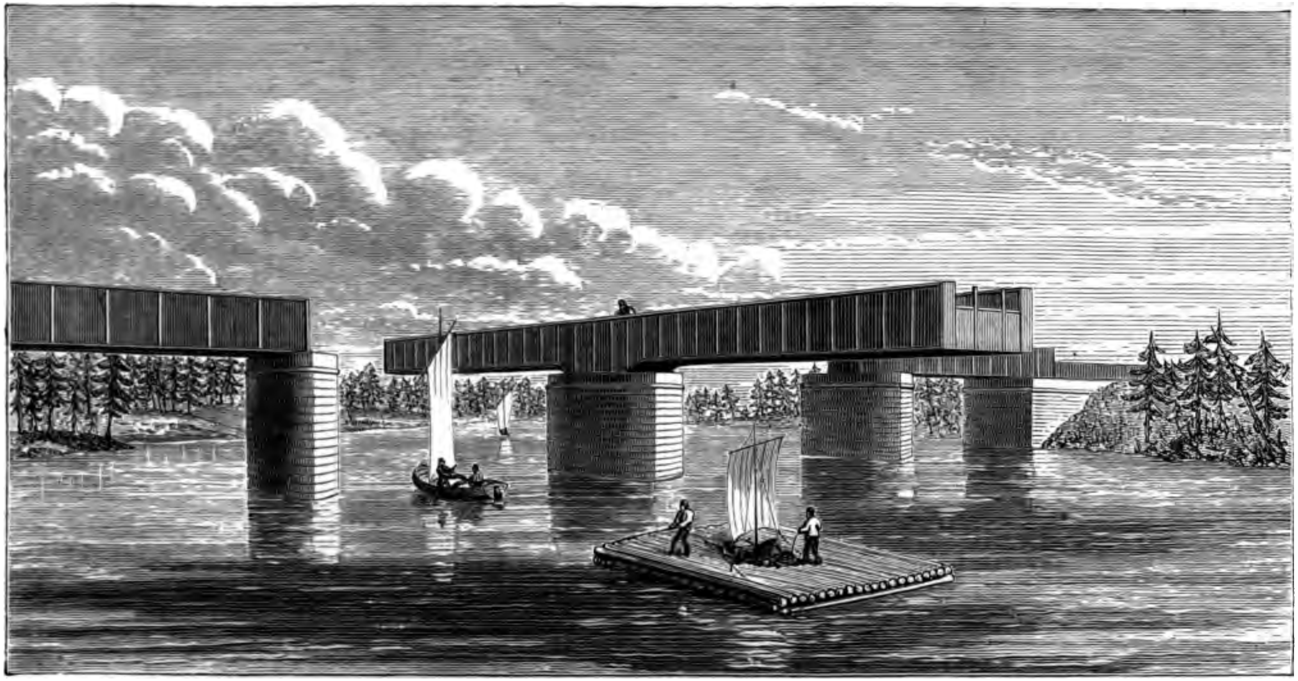


PLATE 21.– DAGLÖSELFVEN.

The movable girders turn on a central table, supported on a live ring and rollers of cast iron.

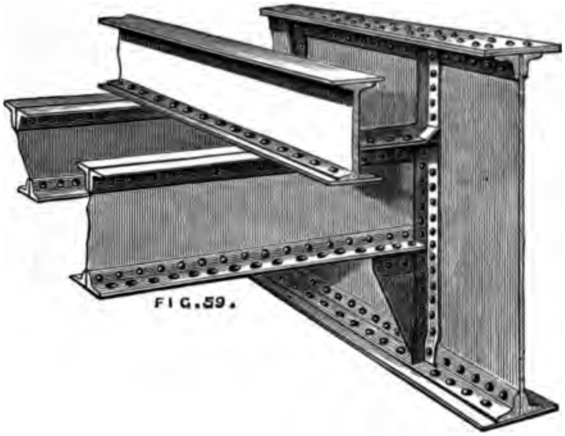
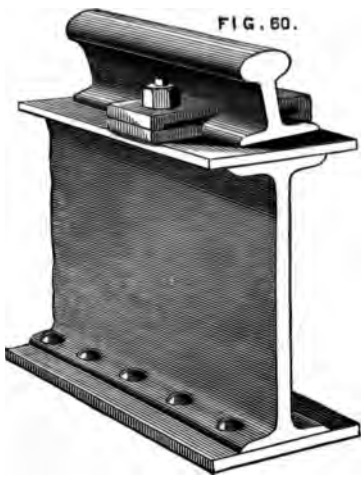


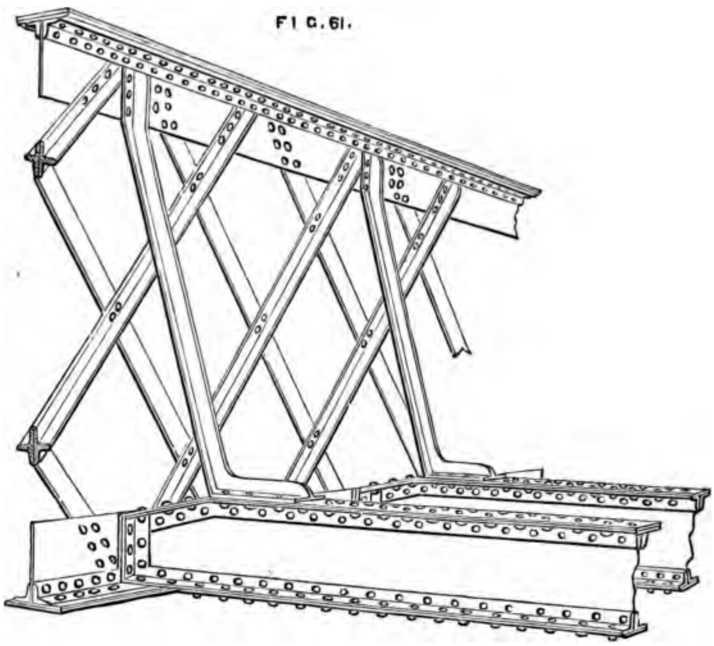
FIG. 59.

FIG. 60.



It is opened and closed by hand by means of rack, pinion, &c., and is furnished with the usual locking gear, relieving apparatus, &c.

At Fig. 59 is shown the mode of connecting the cross, main, and rail-bearing girders on the fixed spans of this bridge.



The cross girders are attached to the webs of the main girders, or rather to the web stiffeners, instead of resting on the top or bottom flange.

The work throughout is of a plain and substantial character, but might have been simplified to some extent in the matter of smithwork.

Plate 22 shows a general view of the Klárelfven, another of this series, and Figs. 60 and 61 details of the same bridge.

The designs were by Lieut. Almquist, the engineer of the Bergslagernas line, and the girders were delivered by the Skerne Company in various parts of Sweden as required from time to time.

PLATE 22.—KLÅRELFVEN.

With bars, angles, plates, &c. at an all-round price of £10 10s. per ton, the contract price of these girders was £18 per ton delivered at Gothenburg.

LEITH DOCKS SWING BRIDGE.

The opening span of this bridge is the widest yet attempted in the United Kingdom.

There are several of wider span crossing the Mississippi at various points, and there are probably others which equal or exceed it in the United States.

The Leith Docks Bridge was designed by Mr. A. M. Rendel, C.E., and constructed by the Skerne

Company, under the resident inspection of Mr. Robertson, C.E., of Edinburgh.

It consists of one opening of 120 feet clear, and carries two lines of railway, a roadway, and two footways.

General views of the bridge are shown at Plates 23 and 24. It is opened and closed by means of hydraulic apparatus, constructed by Sir W. G. Armstrong & Co., Newcastle-on-Tyne.

Sections of the main booms &c., are shown at Fig. 62.

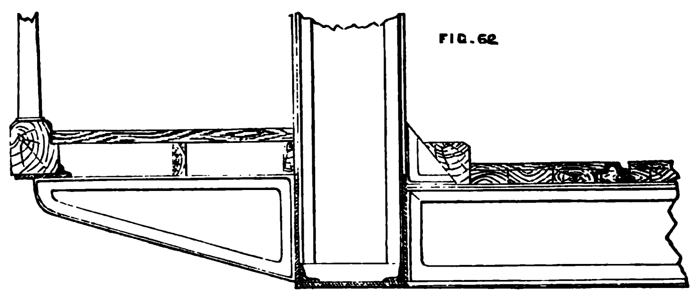


FIG. 62

The flooring is of Memel timber sheathed with greenheart.

The total weight of the swinging portion of the bridge is about 573 tons, composed of 323 tons of wrought and 250 tons of cast iron.

There are about 3,326 cubic feet of timber in the floor, &c.

The contract sum for the Leith Docks Bridge was £8,143, the price for the wrought iron being about £19 per ton erected.

This was based upon plates at £9 10s. and angles at £8 10s. per ton.

Plate 23.—Leith Docks Swing Bridge.

PLATE 24.—LEITH DOCKS SWING BRIDGE.

GIRDERS FOR THE STATE RAILWAYS OF INDIA.

Allusion has already been made to some of the girders made for the metre gauge railways of India at the Skerne Works.

FIG. 63.

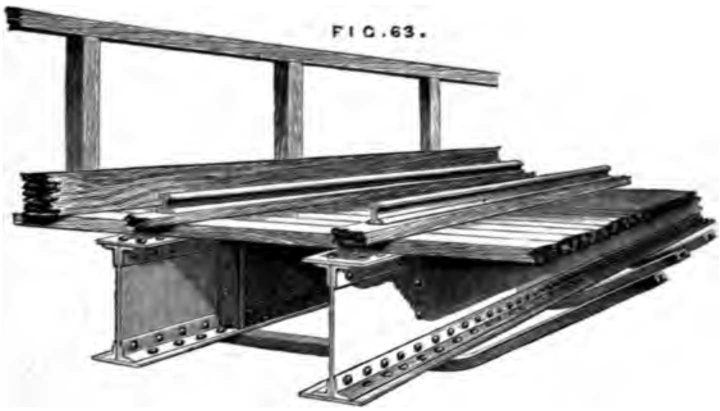
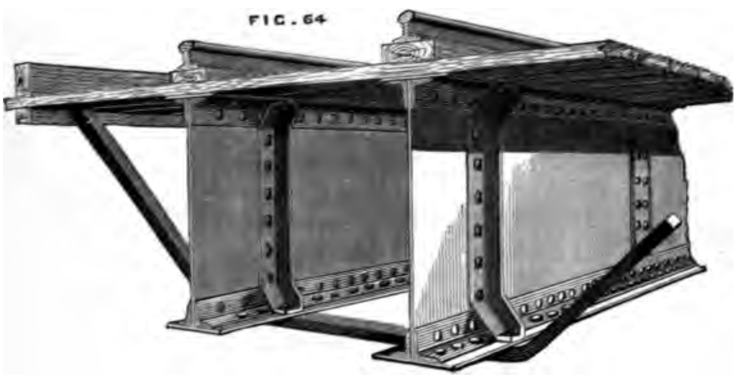


FIG. 64



They consisted chiefly of plate girders of 6 and 12 metres (Figs. 63, 64, 65, 66), and triangulated girders of 18, 28⅓, 30, and 40 metres respectively (Figs. 11, 12 :

pages 17, 18). Large numbers of most of these sizes were made to Mr. Rendel's order.

From the point of view of the practical constructor, these girders are all of most excellent design.

The various sections of iron used are such as can be most readily obtained, and at the lowest market

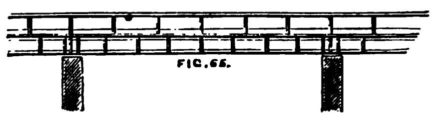


FIG. 65.

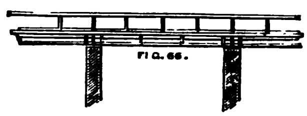


FIG. 66.

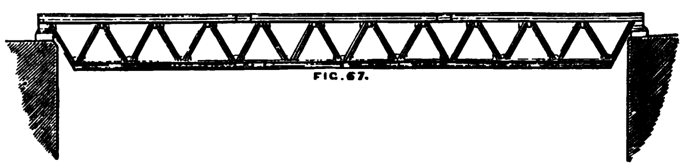


FIG. 67.

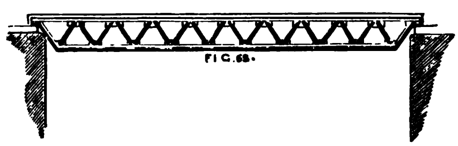


FIG. 68.

price, whilst with regard to workmanship, there is almost no smithwork, and hardly a rivet that could be dispensed with.

Besides these commendable features, the erection, owing to the small number of rivets to be put in at site, and the lightness and portability of each riveted piece, could not fail to be quickly and economically accomplished. In fact, the designs in any of the points which we have to consider here could hardly be improved.

The following table shows the tests to which the iron used in construction was subjected :—

	Tensional strains. Tons per square inch.	Percentage of contraction.
Rod and bar iron	24	20
Angle and tee iron	22	15
Plate iron	21	10

These tests were conducted by Mr. Kirkaldy, of Southwark.

The whole of the rivet holes in the angle iron booms, all those in the gusset plates, and all those in the triangulated bracings, by which the latter are riveted to the gussets, and all those in the cover plates, were drilled. The remainder of the rivet holes were punched.

The girders were all constructed with a camber, that of the 18 metres being 3 centimetres, and the others in proportion.

The spans were tested with weights up to 5,000 grammes per lineal metre, equal to 1½ tons per lineal foot.

With materials at £11 18s. per ton, the contract prices were as follows :—

The 18 metre girders, £17 10s. per ton.
The 30 metre girders, £18 per ton.
The 40 metre girders, £18 10s. per ton.

All delivered free on board in London.

WIDENING OF CARLISLE BRIDGE, DUBLIN.

A general view of this bridge, with a section through one of the caissons constituting the extension to the width of the piers, is shown at Plate 25.

This work was executed to the order of Mr. B. B. Stoney, C.E., of the Dublin Port and Dock Board.

The caissons (Fig. 69) were framed together and

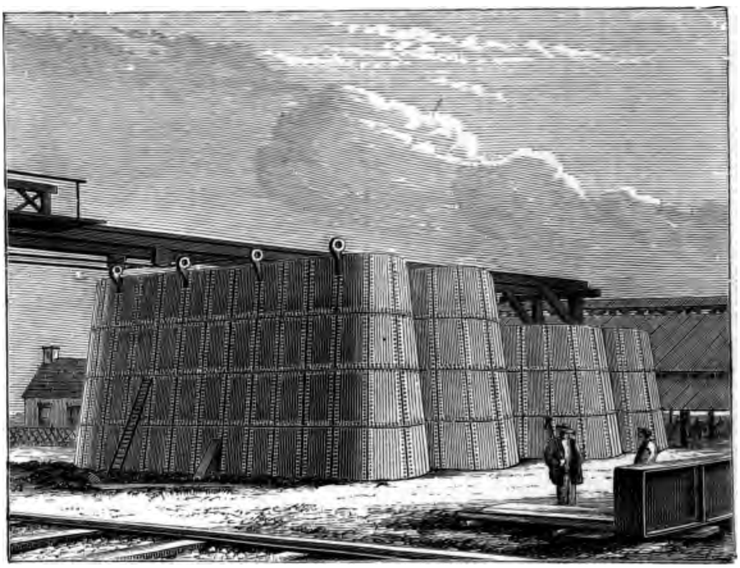


Fig. 69.

riveted up, in a strong platform, 13 feet above low-water, and about 12 feet above high-water mark.

When ready for lowering, a strong staging, composed of sixteen vertical 12-inch timbers, was erected, and a platform built over the caisson.

From this platform the caisson was first lifted off

PLATE 25.

WIDENING OF CARILSLE BRIDGE, DUBLIN.

the bottom platform, by means of eight screws of 2 in. diameter each, and then the bottom platform being removed, lowered down 10 feet at a time to its position on the rock, of which the river-bed is composed.

The overlaying stratum of mud was then cleared away by diving and dredging operations, and the caissons filled with concrete.

These caissons cost £14 15s. per ton erected on the staging ready for lowering.

SWING BRIDGE ACROSS THE RIVER LIFFEY, AT DUBLIN.

This bridge (Plate 26) consists of two main girders, each 124 feet long over all, the centre pier being 40 feet in diameter, leaving a clear available width of opening of 40 feet on each side.

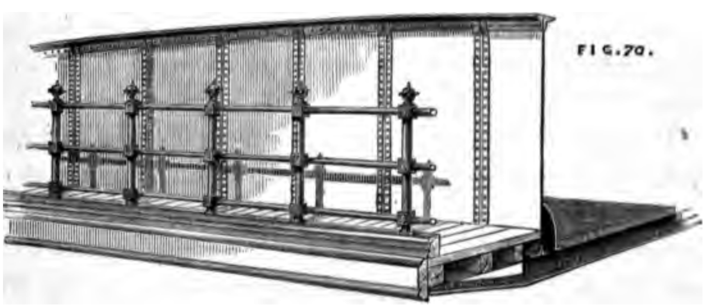


FIG. 70.

The bridge has a clear roadway of 20 feet between the main girders; the footways, one on each side, being carried by cantilevers outside the main girder (Fig. 70), and are 6 feet each in width.

The main girders are formed of plain webs, stiffened by tie bars, the top flange being curved. The depth of main girders in centre is 9 feet.

The bottom flange is formed by ½-inch plates, which are carried by cross girders 2 feet apart.

The ends of the cross girders projecting beyond the main girders from the cantilevers carry the footways.

The swinging girders are carried on a turntable of wrought iron 29 feet in diameter, which moves on a cast iron foot and four steadying rollers, each 4 feet in diameter.

Fixed to the cross girders is a circular cast-iron rack, 33 feet in diameter, into which gears a malleable cast iron pinion, 15 inches in diameter.

This receives its motive power from a double cylinder, vertical, reversing engine, contained in an ornamental engine-house, placed in the centre pier in such a position as to clear the bridge when swinging round.

Locking gear is provided at each end of the bridge. The bridge may also be opened by hand, a crab being placed in the engine-house for this purpose.

The position of the bridge is indicated on a brass dial, with bell apparatus placed in the engine-house.

The Beresford Bridge was built [illegible] design of Mr. B. B. Stoney, C.E. [illegible] and Dock Board; the [illegible] Wm. J. Doherty, A. [illegible] per ton, these [illegible]

PLATE 26. — SWING BRIDGE ACROSS THE RIVER LIFFEY, D

PIER AT LLANDUDNO.

Plate 27 shows a general view of this pier, the wrought iron work ofwhich was prepared at the Skerne Works, to the order of the general contractor, Mr. John Dixon, of London.

It was opened to the public in 1877.

The wrought-iron girders, constituting the part of the work executed by the Skerne Company, are of one type, as shown at Fig. 71.

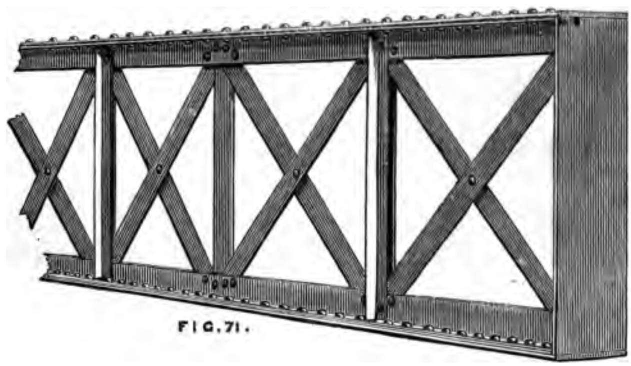


FIG. 71.

The total weight of wrought iron is about 313 tons.

The contract price was £13 5s. per ton delivered at Llandudno, based upon plates at £7 5s. per ton and angle iron at £6 12s. 6d. per ton.

THE PILMORE BRIDGE.

This is a small roadway bridge across the River Tees, near Darlington.

It was designed by Messrs. Robinson and Ianson, civil engineers, of that town, and constructed and erected by the Skerne Company, under the supervision of the senior member of the firm of engineers, Mr. Robert Robinson, C.E. A general view is given in Fig. 72.

FIG. 72—THE PILMORE BRIDGE.

There are four spans, the two land spans being each 52 feet in length, and the two centre ones each 50 feet.

The piers are of a cross section, formed of four bars of angle iron riveted together, which are driven as piles into the bed of the river.

The distance moved by each blow of the pile driver was taken as an indication of the dead weight each pile would be capable of sustaining.

The bed of the river is composed of stiff clay, full of water-worn stones of various sizes, and screw or other flanged piles would have been of very difficult application.

Plate 27. — Pier at Llandudno.

The two piles forming each pier are braced together above the ground line.

The Tees at this point is of no great depth, but rises not unfrequently after heavy rain to nearly the floor level.

The greatest danger, however, which threatens this bridge arises from ice, which, coming down the river in large floes at the breaking-up of a frost, is apt to accumulate at the pier, and exert enormous pressure thereon.

The main girders are of a light lattice form, and are shown by one of the stand-byes, which are provided at each pier, at Figure 73.


FIG. 73.

The top rail is of oak, with cast iron caps at every vertical stiffener of the main girders.

The platform is of Memel timber 3 inches thick, sheathed with oak 1½ inches thick, and carried by light cross girders.

The relative merits of iron and wooden floors for bridges of this character have often been discussed.

The cost of an iron floor, whether of Mallet's buckled or simple curved plates, would greatly exceed that of such a wooden floor as used in the construction of the Pilmore bridge; and it may well be questioned whether the corresponding increased durability is commensurate with this.

A wrought-iron plate, a quarter or five-sixteenths of an inch thick, will, unless constantly repainted or tarred, corrode very rapidly when exposed to the atmosphere, and experience teaches that due attention is seldom paid to such points in practice.

A wooden floor also offers great facilities for repairs, which can be done from time to time as occasion requires, without interfering with the traffic over the bridge, whereas an iron floor would have probably to be renewed *in toto*, causing in many instances long and serious delay.

The strength of this structure was satisfactorily proved soon after it was completed, by the flood of November, 1875, when the water rose 14 inches above the underside of the girders, and subsequently by a flood accompanied by large quantities of ice. The total cost of the bridge was £1,730.

THE HUELVA PIER.

(*The following description is chiefly from* THE ENGINEER *of May* 12, 1876.)

The Huelva Pier is intended for the shipping of copper ore, and was partially opened for duty last month.

It is composed of cast-iron screw piles and columns, and wrought-iron lattice girders; the total length of the screw pile portion from the shore to the pier head being 1,900 feet.

It first bears west for a distance of 650 feet, and then with a curve of 600 feet radius, takes a turn to the south, following the channel of the River Adiel.

For working the mineral trains and shipment of ore on the pier, advantage is taken of the action of gravity, the system adopted being that in use for a similar purpose on the "Tyne."

There are seven lines of way on the pier, at three different levels.

Those on the lower floor, beginning first with one line and then branching out into three, are about five feet above ordinary high-water mark, and are intended for import traffic, while those on the two upper floors are in varying gradients to facilitate the working of the mineral trucks.

The method of working the traffic is as follows :—

Along the two centre lines full waggons are passed to the standage portion. Afterwards a truck at a time is allowed to run down the gradient, thus acquiring an impetus which causes it to mount the steep gradient at the pier head, and on its running down back again, which it does almost immediately, it is switched into one of the two outside roads and spragged, so as to come to rest of itself over one of the divisions of the spout into which its contents are shot, by allowing the hopper door in the bottom of the waggon to fall.

When the door is replaced and the sprag withdrawn, the waggon runs away, owing to gravity, along the outside road towards the shore end.

There are four sets of shipping spouts, constructed so as to allow for varying level of the tide and the difference in the heights of the vessels, a difference which is considerable between a vessel unloaded at high-water spring tides, and one loaded at neap tides.

Each set of spouts has four fixed divisions, as well as a movable spout at the end, which slides in a frame turning on a pivot, and may be raised or lowered in guides by inches to any one of the four divisions to receive the mineral, the lower end being directed to the ship's hold.

An angle of about 30 degrees is found to be the most suitable inclination for the discharge of the ore.

The cast-iron piles are 17 feet long, 16 inches in diameter, and of 1¼-inch metal.

The blades are 5 feet diameter, and were cast loose for convenience in shipping.

The blades are fixed to the ends of the shafts by a couple of bolts, and have two flat sides to receive them, and prevent their slipping when being screwed into the ground.

Different lengths were added to the piles till they were about 32 feet below the surface, and to the top of them columns, 15 inches diameter and of 1-inch metal, were bolted by flanges, the first joint being after the nature of a ball and socket, to admit of the columns being erected perfectly upright, in case the piles should have canted in any degree during the operation of screwing.

These piles and columns are placed in rows of four, alternately 15 feet and 50 feet apart centre to centre, forming as it were a series of piers 50 feet from each other.

Eight of these piles and columns are firmly braced together by tie-rods and struts.

The great feature about the Huelva Pier is the method which has been adopted by Mr. Bruce to secure a good foundation.

The bed of the river is composed of mud, and it was found, on a test pile being screwed down, that it would safely bear only 5 cwt. per superficial foot. As a sufficient bearing surface could not conveniently be given by screw blades, whole balks of pitch pine were strongly fastened together on the surface of the water round each set of eight piles, thus forming a platform which was weighted with rails and pig iron, laid on trestles specially constructed for the easy removal of the iron after the sinking of the platform under the surface of the water.

More weight was added, until each platform, 50 feet by 30 feet, carried 500 tons, which is in excess of the greatest weight of engines, mineral waggons, and superstructure that it will ever be called upon to sustain.

The load was allowed to remain until there were no further signs of sinkage, sometimes so long as two or three months.

Rectangular plates of cast iron were lowered through the water on to the platform, and bolted under collars cast at certain distances apart on the piles to receive them.

These plates were fixed in position by divers, and the whole weight of the superstructure was brought to bear upon the platform by their means.

Near the shore end, where the ground is of a slightly

through pockets arranged in the lattice girders, as shown in the drawings.

The upper lines of rails are fixed in the same kind of longitudinal runners, but rest on cross baulks laid on the tops of the girders.

The platforms carrying the outside roads, which are intended only for the return empty waggons, project 5 feet on each side of the girders.

Longitudinal angle-iron runners are fastened to the ends of the cross timbers for the purpose of steadying them, and these, again, are fastened at intervals to timbers suspended from the top middle floor girders.

All the timber used in these floors is creosoted Memel.

Where the single line branches out into three on the lower floor, the columns are necessarily dispensed with, and the main girders of the floors above are carried by double T girder frames spanning the turnouts.

Around the pier head is constructed a timber shipping deck. It is kept from actual contact with the iron structure, with a view to prevent any blows or shocks from ships being communicated to the same.

Creosoted Memel piles, with cast-iron screw blades 4 feet in diameter, have been used for the deck.

These piles, which are arranged in double rows, are firmly braced together by wooden ties and struts in all directions.

The deck is covered with 3-inch planking, and a pair of rails are laid for carrying a steam travelling crane. A traverser also runs on the deck and the lower floor of the piers, for shifting waggons from one line of way to another on the same level. A 10 tons' erected by the Skerne Company, under the supervision of the senior member of the firm of engineers, Mr. Robert Robinson, C.E. A general view is given in Fig. 72.

FIG. 72—THE PILMORE BRIDGE.

There are four spans, the two land spans being each 52 feet in length, and the two centre ones each 50 feet.

The piers are of a cross section, formed of four bars of angle iron riveted together, which are driven as piles into the bed of the river.

The distance moved by each blow of the pile driver was taken as an indication of the dead weight each pile would be capable of sustaining.

The bed of the river is composed of stiff clay, full of water-worn stones of various sizes, and screw or other flanged piles would have been of very difficult application.

The two piles forming each pier are braced together above the ground line.

The Tees at this point is of no great depth, but rises not unfrequently after heavy rain to nearly the floor level.

The greatest danger, however, which threatens this bridge arises from ice, which, coming down the river in large floes at the breaking-up of a frost, is apt to accumulate at the pier, and exert enormous pressure thereon.

The main girders are of a light lattice form, and are shown by one of the stand-byes, which are provided at each pier, at Figure 73.

FIG. 73.

The top rail is of oak, with cast iron caps at every vertical stiffener of the main girders.

The platform is of Memel timber 3 inches thick, sheathed with oak $1\frac{1}{2}$ inches thick, and carried by light cross girders.

The relative merits of iron and wooden floors for bridges of this character have often been discussed.

The cost of an iron floor, whether of Mallet's buckled

The total cost, including timber, machinery, &c. was about £163,000, that of the girder work being at the rate of £18 per ton, delivered in London; iron being at that time at an extremely high price.

Two views of the Huelva Pier are given on Plates 28 and 29.

SWING BRIDGE OVER THE RIVER OUSE, NEAR YORK.

Plate 30 shows a view of this bridge, which carries the main line of the North-Eastern Railway over the River Ouse at Naburn, near York.

It consists of one fixed span of 107 feet, and two swing openings of 88 feet each over all.

Motion is given to the swing girders by means of combined steam and hydraulic machinery contained in the centre pier, which is situated on the northern bank of the river.

The system adopted is that of a centre pin with a live ring and rollers, the hydraulic engines operating upon a circular rack fixed to the carrying girders.

The bridge may also be opened by means of a hand windlass.

The river pier is formed of two cast-iron cylinders sunk in the bed of the river to a great depth, and filled with brickwork in cement and braced; the girders resting on granite blocks bedded in the brickwork.

The main girders are of the hog-backed, single webbed form, as regards both the fixed and movable spans.

The platform is composed of cross girders, rail bearers, and curved flooring plates; the cross girders resting on the bottom flange of main girders, and being riveted to the webs.

Over the centre of the main pier, carried by arched girders, is the signal cabin and engineman's room.

From this, all the operations connected with signalling, opening, closing, and locking the bridge are conducted.

The whole of the work is of an extremely massive and substantial character, and forms in this respect a striking contrast to many structures designed for similar work on the Continent of Europe, and especially in America, where probably not much more than half the weight of material would have been used.

Wherever practicable, the rivet holes were drilled through all thicknesess at one operation.

For this purpose, portable steam-drilling machines were made specially for the holes in the curved-top booms of the main girders.

The total weight of wrought iron in main girders and platform is about 402 tons; of cast iron in the piers, accumulator, balance-weights, &c. 260 tons. Half a ton of steel and seven cwt. of brass were also used in the construction of the rolling apparatus, adjusting pins, &c. &c.

The cylinders below the ground in line with those of the river pier did not form part of the Skerne Company's contract, and the weights are not included.

The whole of the hydraulic and steam machinery was made by Sir William Armstrong and Co., Newcastle.

Plate 30 —Swing Bridge over the River Ouse.

The work was executed throughout to the instructions of Mr. T. E. Harrison, C.E.; the resident engineer being the late Mr. Robert Hodgson, C.E.

AQUEDUCT OVER THE NAHR-EL-KELB, SYRIA.

This aqueduct was constructed by the Beyrout Water Works Company for the purpose of conveying the water over the Nahr-el-Kelb.

It consists of a wrought-iron trough, 105 feet in length, divided into two spans, the ends resting on masonry abutments, and the centre on a masonry pier.

The width of the trough is 5 feet inside and 4 feet deep, the depth of water being 3 feet. The plates of the trough are of $\frac{3}{8}$ inch iron sides and bottom, in lengths of 5 feet $2\frac{1}{2}$ inches, connected with butt joints joined together with T irons 5 inches × 3 inches × $\frac{7}{16}$ inch; the sides and bottom joined by L irons 3 inches × 3 inches × $\frac{1}{2}$ inch. The reason of the plates being in such short lengths was to allow them to be carried by camels from the ship to the place of erection, where they were finally put together.

The top chords are of T irons, 8 inches × 4 inches × $\frac{9}{16}$ inch, connected with each other on top by cross T irons, 3 inches × 5 inches × $\frac{7}{16}$ inch over the ends of each plate.

The joint plates and L irons were sent out riveted on the side plates, so as to reduce the work on the site of erection as much as possible.

All the rivets used were of $\frac{3}{4}$ inch round iron.

The trough rested solid on the pier, and an arrange-

14 inches deep, with ¼ inch webs, and top and bottom flanges, each formed of a pair of 3½ inches by 3½ inches angle irons. The platform is of Memel planking 3 inches thick, carried by longitudinal beams, 11 inches deep by 5½ inches thick, the ends of which are inserted between the flanges of the transverse girders. The platform was covered with a thick coating of asphalte before the metalling was put on.

The abutments are of red brick, with ashlar caps and string courses. Their face walls are 3 feet and the wing walls 2 feet thick at the top, with a batter of 1 in 8. The piers are each composed of two screw piles.

In order to guard against the action of ice, &c. the lower portion of each pile, up to about 5 feet above the water level, is made of wrought-iron plate ½ inch thick. This lower portion of each pile is 1 foot 8 inches in diameter outside, and is filled in with concrete.

The upper portion of each pile, which is of cast iron, is 10½ inches diameter and ¾ inch thick. The transverse girders connecting the piles are 12 inches deep, and the cross-bracing of the lower portions of the piles consists of 4 inch × 4 inch × ½ inch angle irons, and that of the upper portions of flat bars 4 inches × ¾ inch. The piles are screwed down into the bed of the river to depths of from 6 feet to 10 feet.

The contract price for the bridge was £2,520—a remarkably low one for the work done, and only explicable from the fact of the contractors being large iron manufacturers as well as extensive bridge builders. There were no extras charged, and the amount above mentioned included the iron, brick, stone, and timber work; the excavation, labour, erection, carriage, &c.

Plate 31.—Cookham Bridge.

in fact, the cost of the whole bridge complete as it now stands, in addition to the removal of the old structure, which it replaced.

The Cookham Bridge was designed by the writer, and erected under the superintendence of Mr. W. G. Fossick, the present representative of the Skerne Company in London.

Mr. William Atkinson, M.I.C.E., acted as consulting engineer for the Cookham Bridge Company.

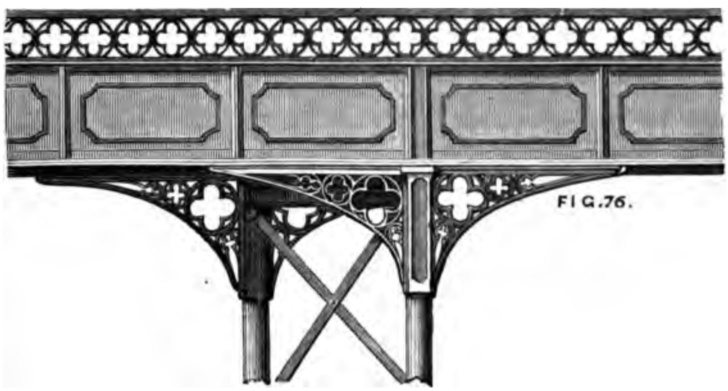


Plate 31 shows a general view of the bridge, and Fig. 76 a portion of one of the piers, with main girders, hand-railing, and cantilever brackets.

OTHER BRIDGEWORK, ETC.

The foregoing are intended to serve as examples of some of the forms of wrought-iron girders or bridges constructed at the Skerne Works.

Many others of a similar class, which in some instances might be measured by miles, could also be mentioned, but they do not perhaps present any structural features of sufficient interest to merit detailed description. Amongst these are numerous bridges for the Nizam's Railway, India; the East Indian Chord line; a portion of the Hooghly floating bridge; and many others in India, New Zealand, &c. &c.

The Works also produce, in large quantities, the usual variety of builders' beams, pontoons, tubes for water-works, gas, irrigation, mining, and other purposes; columns, roofs, tanks, boilers, buoys, cranes, chimneys and flues, iron flooring, &c.

THE SKERNE COMPANY'S WORKS.

These consist of the Skerne Works at Darlington, and the Britannia Works between Middlesborough-on-Tees and Newport.

At the former there are about ninety puddling furnaces, four steam hammers, three plate mills, and an angle iron mill, with the usual accessories, shears, saws, &c.; the whole being capable of turning out from 900 to 1,000 tons of finished plates and angles per week.

Most of the Company's girder-making operations have also been heretofore carried on at Darlington, the productive power of the works being equal to about 4,000 tons per annum of material of this kind.

The Skerne Works stand upon about twenty-two acres of ground, and employ, when at full work, about 1,000 hands.

The Britannia Works have only lately been acquired by the Company.

They stand upon twenty acres of ground, and their productive power is now equal to nearly 2,000 tons of finished iron per week.

There are 120 puddling furnaces, two forge trains, six shingling hammers of six tons each, and sixty boilers, finishing mills, heating furnaces, &c. equal to the above weekly turn-out.

The furnaces are all heated by gas on the Siemen's principle.

These Works are situated on the River Tees, and from their extensive wharf can ship direct into coasting or foreign-going steamers or other craft; an important advantage in these days of keen competition at home and abroad.

ON THE MODE OF ERECTION OF THE LARGE IRON GIRDER RAILWAY BRIDGE OVER THE RIVER DAL IN SWEDEN.

BY MR. EDWARD HUTCHINSON.

(Read before a meeting of the Institution of Mechanical Engineers at Birmingham in 1876, and republished by kind permission of the Council.)

The bridge, the peculiar mode of the erection of which it is the purpose of this paper to describe, is one of a series constructed for the Bergslagernas Railway Company, of Sweden, by the Skerne Iron Works Company, of Darlington.

The main line of this railway connects the east coast of Sweden at Gefle with the west coast at Gothenburg, and runs for the most part through a densely-wooded and thinly-populated country.

The railway crosses the River Dal, the most important stream in Sweden, about ten miles to the west of the town of Fahlun.

At this point the river, elsewhere of much greater width, is about 400 feet wide from bank to bank, and is a deep and rapidly-flowing stream, forming a cataract almost immediately below the site of the railway bridge.

The bridge is for a single line of railway, and is formed of three spans; the two side spans being 80 feet each, and the centre span 208 feet clear opening, with 40 feet height from the water, as shown in Frontispiece.

The abutments are of granite masonry, and are founded upon the solid rock.

The two piers are also bedded upon the granite rock

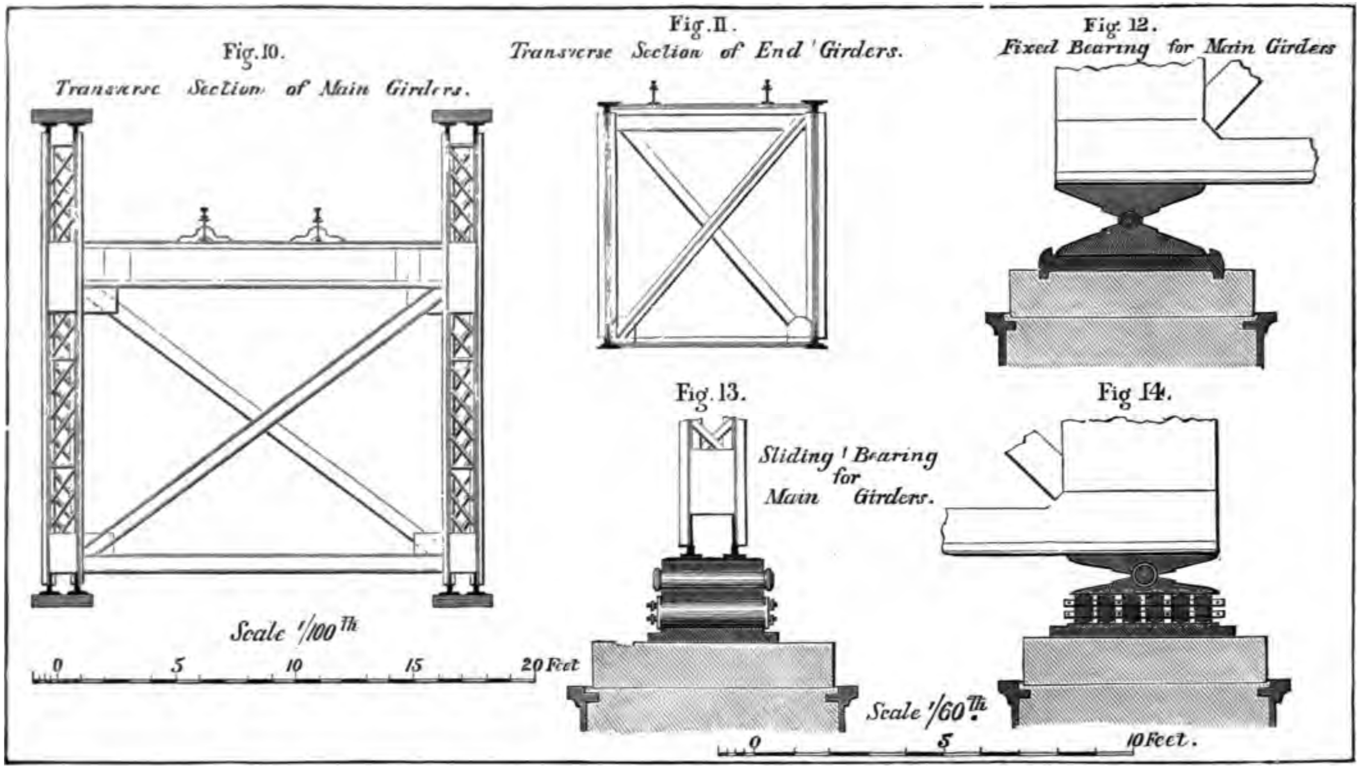


Fig. 10.
Transverse Section of Main Girders.
Scale 1/100th
0 5 10 15 20 Feet
Fig. II.
Transverse Section of End Girders.
Fig. 12.
Fixed Bearing for Main Girders
Fig. 13.
Sliding Bearing for Main Girders.
Fig. 14.
Scale 1/60th.
0 5 10 Feet.

PLATE 32.

which forms the river-bed, and for a height of about 15 feet above low-water level are constructed of granite masonry.

Above this level the piers consist each of two square columns, each 8 feet square, constructed of cast iron plates bolted together at the angles and the horizontal joints, and filled with brickwork in cement.

The girders for the side spans are formed with a double system of bracing, and are 10 feet 6 inches in depth; the top and bottom booms, which are of similar section, are composed of plate and angle iron, as shown in the enlarged transverse section in Fig. 10, Plate 32, and the bracing ties and struts are of **T** iron of varying section.

These girders do not rest directly upon the piers, but are supported by cross bearers fixed between the main girders of the centre span at the height shown in the general view of the bridge (see Frontispiece).

The rail bearers are level with the top flanges of these girders, so that the rail level is 3 feet 10 inches below the top of the main girders.

The main girders, which are fixed 17 feet apart, centre to centre, are also formed of a double system of bracing, and are 19 feet 10 inches in depth, and 2 feet 6 inches in width on the flange, and 214 feet 5 inches length of bearing.

The top and bottom booms are built up of plates and angle iron, and have a double web of angle and plate, to which the bracing bars are riveted, as shown in the enlarged transverse section in Fig. 10, Plate 32.

The bracing is composed in part of **H** iron, in part of angles and flats riveted, and part of **T** or **L** iron.

At each alternate intersection of the bracing a vertical member is introduced supporting the cross girders, which are built of angle and **T** iron, and are 2 feet in depth.

Below each cross girder is a system of vertical diagonal bracing; and horizontal bracing, of which the cross girders form the compression members, runs from end to end of the centre span.

The girder bed-plates are bedded upon the brickwork, and are provided with adjusting apparatus at each end, and with expansion rollers at one end only.

These are shown enlarged in Figs. 12 to 14, Plate 32. The stationary bed-plates are of cast iron, with a steel adjusting pin; but those used in connection with the expansion rollers, as well as the rollers themselves, and the adjusting pins, are of crucible cast steel.

The wrought iron, of which the superstructure of the bridge is composed, was guaranteed by the contractors to stand the following tests:—

For the side spans all plates to bear a load of 20 tons per square inch before fracture, and all angle and bar iron 22 tons; in each case showing an elongation of 10 per cent. before fracture.

For the main span the plates were to bear a load of 21 tons per square inch before fracture, and the angle and bar iron 23 tons; the plates to show an elongation of 10 per cent., and the angles and bars an elongation of 15 per cent., before fracture.

The rolled joists, rivet irons, &c. were also subjected to special tests. The whole of the ironwork was, in the first place, put together in the contractors' yard at Darlington, and subjected to various tests. It was

Diagram of Counterbalance for Half Span of Main Girders.

Fig. 4. Elevation

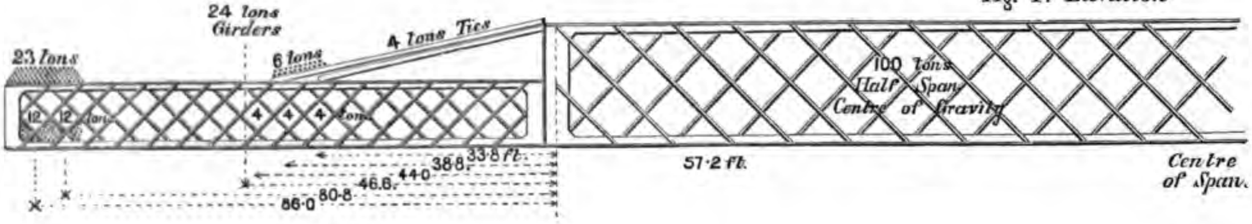
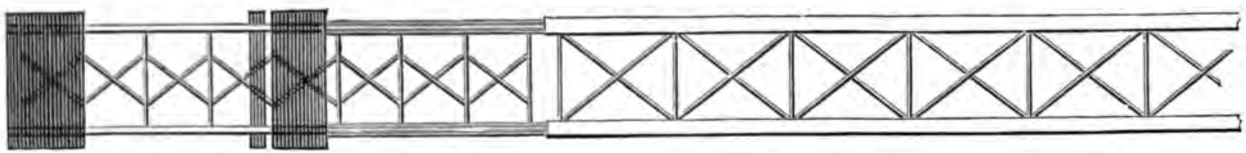


Fig. 5. Plan.



Scale 1/350th

PLATE 33.

then taken down and transported to the site of erection in small pieces.

Owing to the character of the stream to be spanned by the bridge, none of the ordinary modes of fixing girders of this size seemed quite feasible. The erection of the side spans, of 80 feet each, presented of course no difficulty; and, if desired in the case of these spans, staging could easily be erected from the abutment of the pier, as shown. Between the piers, however, 208 feet apart, it seemed impossible to get the smallest prop or support of any kind.

During the summer season, immense quantities of pine timber, either in the form of rafts or loose masses, were continually floating down the river, and would quickly have carried away any staging it would have been practicable to erect.

In the winter the ice presented a difficulty of equal or greater magnitude; and owing to the proximity of the Falls just below the bridge, the ice never became so thick as to afford a safe platform upon which to work.

Under these circumstances, the plan of rolling the girders over the piers was naturally the first to suggest itself, and did not at first appear to present any unusual difficulty. It will, however, be found that in most cases where this plan has been successfully adopted, the superstructure of the bridge has been composed of a number of spans of equal or nearly equal length; and where this uniformity exists, it is not difficult, even in the case of non-continuous girders, to connect two or more spans together in such a way that a whole span length may safely be projected over the pier. Nor does the length of span affect the question much, as the girders are necessarily of a depth and strength proportionate to their span. But when a pair of girders have to be projected a clear 208 feet, with only a pair of 80 feet girders to balance them, the conditions are entirely altered, and, although not impossible, it would not be by any means easy of accomplishment

To meet the difficulty in the case of the Dal Bridge, various schemes were proposed.

The original plan intended by Lieutenant Almquist, the engineer for the Bergslagernas Railway, and to whose designs the bridge was constructed, consisted of a staging carried by chains suspended between the piers. But when worked out in detail, this plan promised to be a most tedious and costly one, and, moreover, would have necessitated the greatest care in its adoption, in order to avoid damage to the piers. It would, in fact, have been almost equivalent to building a suspension bridge of equal strength to that of the permanent structure.

It was also proposed to build all the girders on one side of the river, and to attach them together in the order they occupy permanently in the bridge; then, properly counterweighted, to launch them in the usual way. This plan offered some advantages, but connections of great strength would have been required; besides which, many portions of the girders would have been subjected to severe abnormal strains—an objection which hardly applies at all to the mode of erection ultimately adopted.

Timber being plentiful and cheap in the neighbour-

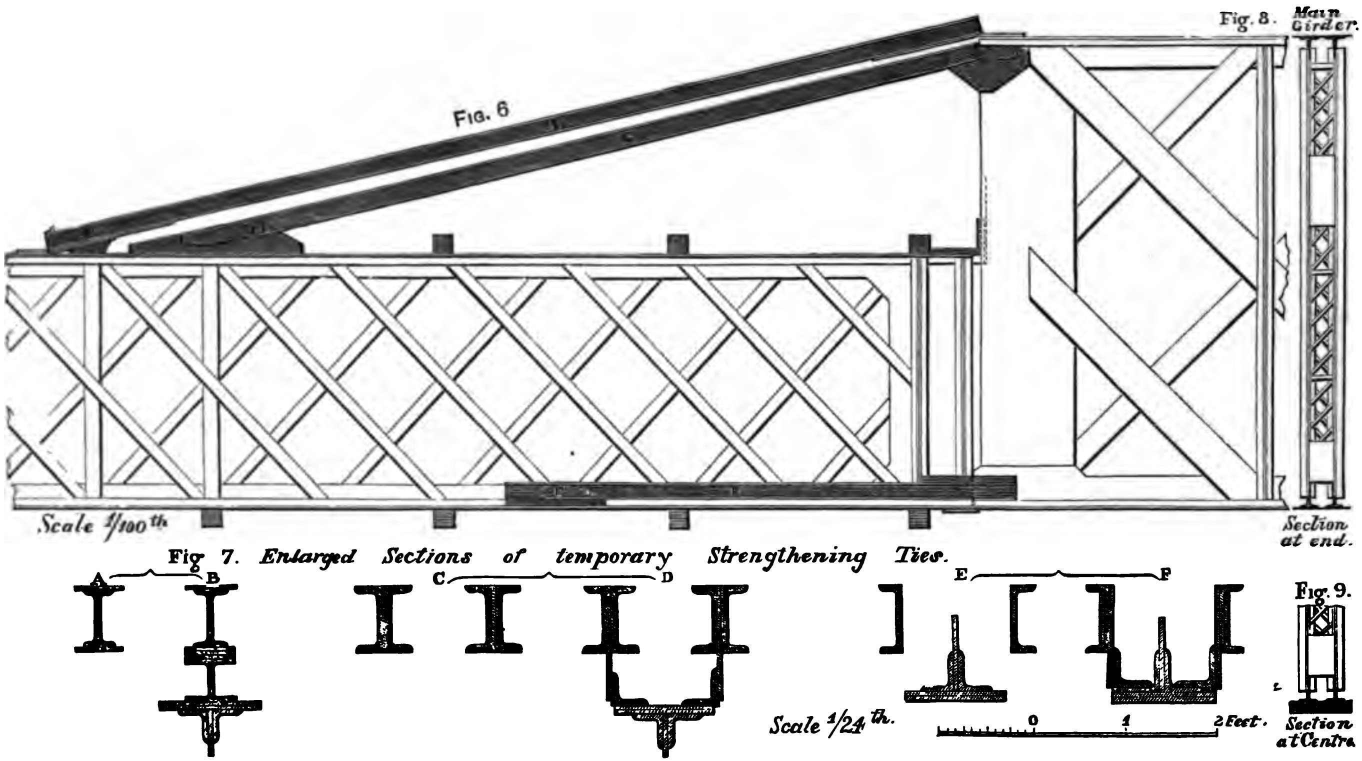


Fig. 6
Fig. 8.
Main Girder.
Section at end.
Scale 1/100th
Fig 7. Enlarged Sections of temporary Strengthening Ties.
A
B
C
D
E
F
Scale 1/24th.
0
1
2 Feet.
Fig. 9.
Section at Centre

PLATE 34.

hood of the bridge, various forms of projecting staging formed of this material were also contemplated, but when worked out in detail, none of them seemed to be altogether unobjectionable. Before the method to be adopted was finally decided upon, the staging between the abutments and the piers, as well as the struts projecting from the piers, were provided by the railway company, it being understood that the girders would be fixed by some sort of rolling operation.

It was, however, ultimately decided to adopt the following plan: Upon the timber staging already provided, the 80 feet girders were riveted up, with their bottom flanges level with those of the main centre girders, as shown on Plate 33, Fig. 4, and on Plate 34, Fig. 6, being temporarily braced together by means of timber struts and the permanent ties, as shown in Fig. 5, at a distance apart corresponding to that of the main centre girders.

Four strong ties were then fixed between the top of the end of the main girders, and a point near the centre of the 80 feet girders.

These ties are shown shaded in Fig. 6 at A, C, and sections of them in Fig. 7 at A, B, C, D. They are all composed of bars, ultimately forming portions of the permanent structure, such as longitudinal rail-bearers, bracing-struts, &c. Special connections, however, had to be provided, and about twelve tons of material of various sections was used throughout for this purpose.

The bottom boom of the 80 feet girders being of insufficient section to stand the compressive strain to which it would be subjected during the process of erection, the strain had to be distributed by means of the compression struts E, Fig. 6, shown in section at E F in Fig. 7 ; these also being composed of parts of the permanent bridge.

The ends of the main girders being securely braced and tied to the 80 feet girders, as above described, it became necessary to distribute the counterweight in such a way that no undue strain should come upon any part of the 80 feet girders ; and in addition to this it was found necessary to strengthen them a little at the centre, near the point of attachment of ties.

The diagram, Fig. 4, Plate 33, shows how the counterweight, composed chiefly of rails, was distributed : 47 tons being placed at the extreme ends of girders, 18 tons near the point of attachment of ties, and 28 tons in the girders and ties themselves, making a total of 93 tons.

The weight of the half main-span, with a fair allowance for tools, &c. was ascertained to be 100 tons ; and the distance of the centre of gravity from bearing point on pier 57·2 feet, as shown in Fig. 4. Care was taken that none of the weight came upon the props that projected a few feet outwards from the piers, as shown in the general elevation, Plate 35.

All being made secure, the process of projecting out the main centre girders was commenced from both piers simultaneously. Each member of the girder was fixed in position in nearly the same form in which it left the works ; that is, no further riveting was done until each piece was in position.

As the riveting-up of the main girders proceeded, the cross girders which had been riveted up at the

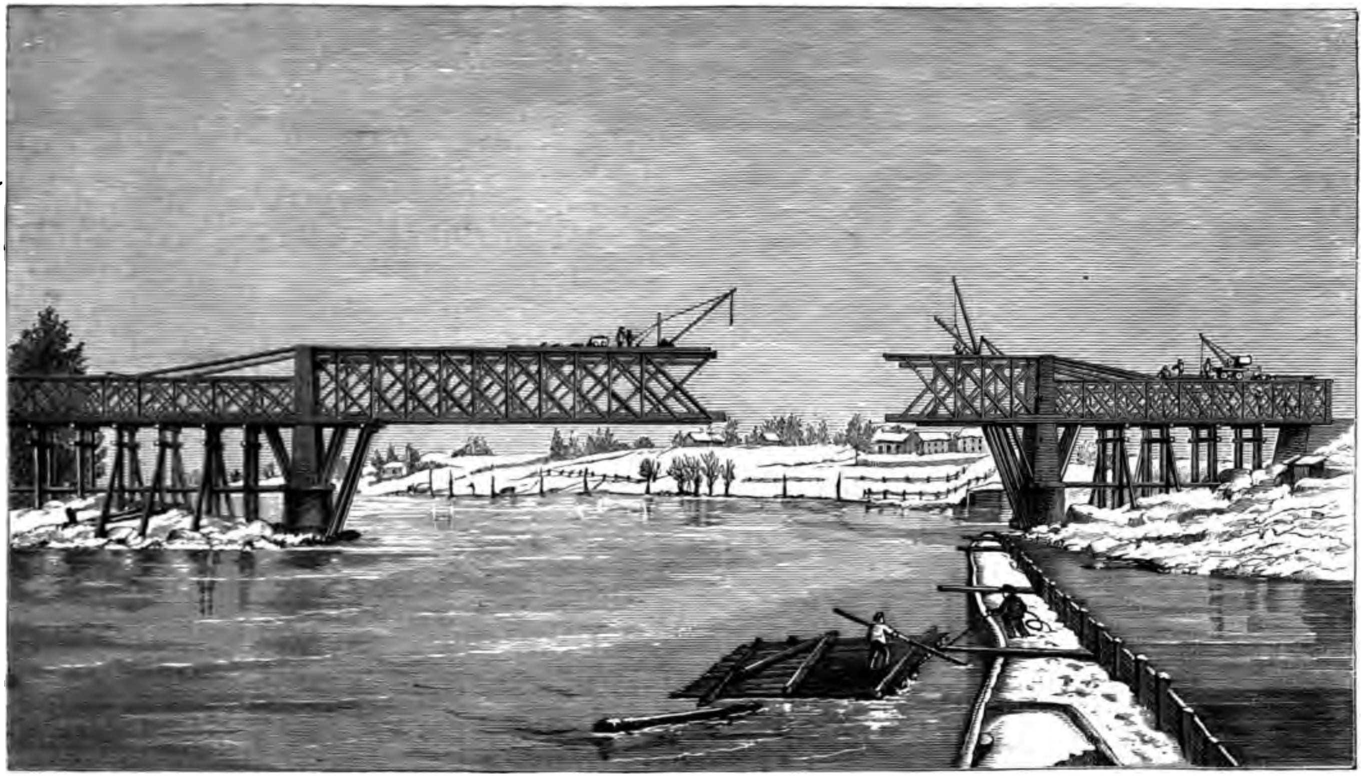


PLATE 35.—BRIDGE OVER THE RIVER DAL.

works were fixed, as well as the rail bearers and such parts of the main horizontal bracing as seemed necessary to give stability to the work. But the main flange plates, as adding greatly to the overhanging weight, without giving any additional strength, were not put on until the girder was in other respects complete.

The weight of the heaviest piece fixed at one operation did not exceed 25 cwt. No special provision in the form of staging for the workmen was provided, planks temporarily laid across the transverse bearers or rail girders being found sufficient for the purpose; but it was deemed prudent by the workmen to test the stability of the girder occasionally, by running out a small truckload of material, weighing about five tons, to the end of the girder. In the first instance, portable cranes were used in moving and fixing the various parts; but better progress was found to be made with long-jibbed Scotch derrick-cranes, and the use of the portable cranes was abandoned.

As the girders during erection rested solidly on the piers, and not upon the rollers, great care had to be exercised in order to fix each half in its correct position as to length. This was done by means of a wire stretched across the river, the operation being repeated several times at various temperatures. When the closing piece came to be fixed in position, it did not fill the space by about an inch; but the following day, under the influence of a bright sun, this gap disappeared, and the closing portions had to be driven into their places.

The bridge was erected during the winter season, and the cold at times was so severe that operations had to be entirely suspended; the days, too, were very short. From these combined causes the erection occupied a much longer time than it otherwise would have done, namely, about five months. When, the main girders having been completed, the temporary ties were cut away, there was only a slight and hardly appreciable deflection at the centre of the main span. No accident of any kind happened in carrying out the work.

In conclusion, the writer, whilst not wishing to take any credit to himself as having accomplished any very important work, at the same time desires to recommend to any who are interested in bridge-building the plan here described for cases where the girders are of considerable length, and staging impracticable.

Mr. S. Z. Lloyd inquired what was the additional strength which was required in the lower flange of the girders in this mode of erecting a span of these dimensions, over what would be required in erecting it upon a stage in the ordinary manner; as the lower boom, which was in tension when the bridge was completed, was in compression during erection, additional material would have probably to be provided to meet that case. He asked whether calculations had been made as to the additional material required in the span for that reason, or whether the design was considered sufficiently strong without such addition.

Mr. Jeremiah Head observed that the sections at the top and bottom of the girder appeared to be the same, and they would therefore bear reversing. The bottom section which was in tension must be considered as weakened in proportion to the area of the rivet holes at each joint. The top was not affected in the same way, inasmuch as the rivets replacing the iron removed there, took their share of the compression. The greater strain which wrought iron in tension would bear as compared with when in compression was thus equalised in the finished structure.

Mr. J. PLATT remarked it had been mentioned that some of the top and bottom plates were left off till the bridge was joined up in the centre, so as to reduce the weight during erection; the bridge during erection had simply to carry its own weight, without any load.

Mr. E. A. COWPER asked for the dimensions of the sections, the details of which it was desirable should be given. It struck him, however, that the girders would be strong enough to carry their own weight for half the length of the bridge, seeing that the bridge was strong enough to carry a railway.

The PRESIDENT observed that some bridges of similar kind in America, which had been subjected to interferences of atmosphere, had been reported on by Captain Galton.

Captain GALTON considered the present communication a very interesting one, as showing a new way of erecting a bridge; and it would be very interesting to know what the cost of this method was, so as to compare the amount of labour expended, and the extra material required with the cost of erecting by staging, because it was quite clear that in many cases of Indian railways such a mode of construction of a bridge might be found very valuable. As regards the strains, of course the bridge during the construction was in a totally different condition from that which it must be in when it had to bear its load; it was not originally formed, he apprehended, for the purpose of resisting those new strains. He should be glad for more particulars to be given as to the strains to which the girders were subjected when in the process of erecting, and those to which they were subjected after the bridge had been erected. In addition to the cost of labour and materials, he should also like to know the number of men employed, and other particulars, so that a calculation might be formed as to the cost of erecting a bridge in this manner, to afford a comparison with the cost of other methods of putting the work together, which could not be estimated from a mere statement of the weight of materials employed.

Mr. F. J. BRAMWELL referred to the specimen bridge built by the elder Brunel on the grounds of the Thames Tunnel at Rotherhithe. This specimen consisted of a pier and of the half of an elliptical arch on the one side, and about a quarter of a similar arch on the other. These arches were of considerable span, probably 60 feet; they were constructed without any centering, simply of brick in cement, bonded with hoop iron. From the end of the smaller section of the arch was suspended an immense mass of iron to balance the weight of the half arch on the other side.

The PRESIDENT, in proposing the usual vote of thanks for the paper, observed that it contained very important facts, and the subject had been dealt with in a very clear and unbiassed manner. He thought the author had brought before the Institution something which admitted of application, as Captain Galton had said, under a great variety of circumstances, and in many other places. He proposed that the vote of thanks should be accompanied by a request to the author to supplement the paper with the additional information which had been asked for in the discussion.

The vote of thanks was passed.

SUPPLEMENT.

The sectional areas of the top and bottom booms of the main girders (which are equal) are 88·5 square inches at the centre, and 32·2 square inches at the ends; the centre having six plates 30 × ⅜ inches each, and the ends only one plate 30 × ⅜ inches. During erection these plates were omitted, leaving the sectional area only 2·10 square inches throughout each of the booms. During the erection the only abnormal strain was a compression strain upon the bottom of the small girders at E, F, Fig. 6. The sectional area of this is only 16·37 square inches, and as the strain in compression required about 25 square inches, the additional area was obtained by putting on two channel-iron bars of 12·25 square inches total area, one on each side, as shown at E F, in Figs. 6 and 7, thus making a total sectional area of 28·62 square inches.

The sectional area of each of the temporary ties A C was 27·17 square inches, being composed of one bar of I iron, and two pairs of bars of channel iron. In the calculations for the erection of the bridge no part was subjected to a greater strain than 5 tons per square inch, compression or tension.

In the calculation of the counterbalance weight, 80 tons only has to be taken for the weight of each half of the main girders during erection, instead of 100 tons of the total finished weight, on account of all the top and bottom flange plates and much of the bracing being omitted until the junction of the two halves in the centre was effected. The calculation for the counterbalance was as follows :—

		Tons.		Feet.		Total.
Half main girders		80	×	57·2	=	4576
Counterbalance :—						
Side girders		24	×	46·6	=	1118·4
End weights		23	×	83·4	=	1918·2
		12	×	86·0	=	1032·0
		12	×	80·8	=	969·6
Middle weghts		6	×	36·8	=	220·8
		4	×	44·0	=	176·0
		4	×	38·8	=	155·2
		4	×	33·8	=	135·2
Ties		4	×	18·5	=	74·0
					=	5799

As to the cost of erection, this is considered to have been about the same as a fair average of such work erected by any of the ordinary methods. It is difficult, however, to make a fair comparison, as so much depends upon the distance from home, cost of getting materials and tools to the spot, season and weather, &c. The labour in putting together, riveting, &c. was little more than it would have been on staging, and the chief difference in cost would be that between the temporary iron ties, &c. and wood staging.